Environmental Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Heavy metals exposures among Mexican farmworkers in eastern North Carolina

Sara A. Quandt [a,*], Bradley T. Jones [b], Jennifer W. Talton [c], Lara E. Whalley [d], Leonardo Galván [e], Quirina M. Vallejos [d], Joseph G. Grzywacz [d], Haiying Chen [c], Kathryn E. Pharr [b], Scott Isom [c], Thomas A. Arcury [d]

[a] *Department of Epidemiology and Prevention, Division of Public Health Sciences, Wake Forest University School of Medicine, Winston-Salem, NC 27157, USA*
[b] *Department of Chemistry, Wake Forest University, Winston-Salem, NC, USA*
[c] *Department of Biostatistical Sciences, Division of Public Health Sciences, Wake Forest University School of Medicine, Winston-Salem, NC, USA*
[d] *Department of Family and Community Medicine, Wake Forest University School of Medicine, Winston-Salem, NC, USA*
[e] *North Carolina Farmworkers Project, Benson, NC, USA*

ARTICLE INFO

Article history:
Received 22 February 2009
Received in revised form
1 September 2009
Accepted 14 September 2009

Keywords:
Agriculture
Occupational health
Biologic monitoring
Health disparities
Environmental justice

ABSTRACT

Background: Immigrant farmworkers are a population at risk for numerous environmental and occupational exposures. The metals arsenic, lead, mercury, and cadmium are known neurotoxins to which workers can be exposed both in the US and in their country of origin. Because farmworkers are exposed to neurotoxic pesticides, they may be at risk for adverse health effects from the combined exposure.

Objectives: To examine the relationship between exposure to metals, as measured in urine, with personal and work-related characteristics of Mexican migrant and seasonal farmworkers in the US.

Methods: We analyzed data on metals found in urine of 258 farmworkers recruited from 44 camps in eastern North Carolina in 2007. Geometric means and 95% confidence intervals (CI) were used to compare data with data from the National Health and Nutrition Examination Survey (NHANES). We used multivariate regression models fitted for each metal to estimate the association of creatinine-corrected urinary metals and worker characteristics related to environmental and occupational exposures.

Results: Geometric mean urinary metals concentrations (μg/g creatinine) exceeded NHANES reference values for arsenic (13.23 [CI 11.11, 15.35] vs. 8.55 [CI 7.23, 9.86]) and lead (1.26 [CI 1.08, 1.43] vs. 0.63 [CI 0.60, 0.66]). Age, being from the central region of Mexico, and pack years of cigarette smoking were significant predictors of metals exposure; being a current smoker and years worked in US agriculture were not.

Conclusions: This first study to examine indicators of worker body burdens of metals shows that workers have body burdens related to exposures other than work in the US. Further research should address their risk for adverse health outcomes due to combined exposures to neurotoxins in pesticides.

Introduction

Humans are exposed to the metals arsenic (As), lead (Pb), mercury (Hg), and cadmium (Cd) through both naturally occurring sources and sources resulting from human industrial, and cultural activities. These metals are toxic at acute high exposure levels, and increasing evidence points to negative health effects from cumulative, lower level exposure (Hu, 2002). Their importance as common toxins with a high potential for human exposure is highlighted by their ranking first (As), second (Pb), third (Hg), and seventh (Cd) on the priority list of substances found in hazardous waste sites (ATSDR, 2007a). The exposure of farmworkers to metals is of interest because of their possible occupational exposure, their origins in areas where the potential for exposure to environmental sources is high, and the possible interaction of such toxic chemicals with pesticides to which farmworkers are routinely exposed (Arcury et al., 2009).

Chronic exposure to As is associated with increased risk of reproductive problems, such as miscarriage, stillbirth, preterm birth, and low birth weight, and with chronic diseases such as cancer (skin, bladder, and lung) and diabetes (ATSDR, 2006; Navas-Acien et al., 2008). Neurological effects such as learning and behavioral deficits have been documented (Wasserman et al., 2004; Calderón et al., 2001; Tsai et al., 2003). Pb is a well-established neurotoxin that has serious effects on child development. Recent research has documented the cumulative adverse

* Corresponding author. Fax: +1 336 713 4157.
E-mail address: squandt@wfubmc.edu (S.A. Quandt).

0013-9351/$ - see front matter © 2009 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2009.09.007

effect of Pb on cognitive function in adults (Shih et al., 2007). Hg's neurotoxic effects are well established for child development; for adults, effects include impaired concentration and performance of neuromotor function, as well as paresthesia (Mahaffey, 2005). Cd exposure has been linked to an increased risk of lung cancer (Wild et al., 2009), prostate cancer (Goyer et al., 2004), reduced pulmonary function (Lampe et al., 2008), and all-cause, cardiovascular disease, and cancer mortality (Il'yasova and Schwartz, 2005; Menke et al., 2009).

The biological half-lives of these metals vary, and the amounts excreted can reflect a combination of recent and past exposures. The half-life of Cd is one to four decades, and urinary excretion reflects long-term exposures (ATSDR, 2008). Pb has a short half-life (one to two months) in soft tissue, but that in bone ranges from years to decades. Urinary Pb reflects both short- and long-term exposure (ATSDR, 2007d). The half-life of Hg is one to three months; organic forms (e.g., from seafood consumption) are rapidly excreted, so that urinary Hg reflects mostly inorganic forms (ATSDR, 1999). Similarly, organic forms of As are excreted quickly; inorganic forms are mostly excreted within several days, though some continue to be excreted months or longer (ATSDR, 2007c).

Migrant and seasonal farmworkers from Mexico represent a population at risk of exposure to these metals through environmental, occupational, and cultural sources. Mexico is a leading producer of Pb, and the process of refining produces dust that contaminates the environment, including water sources (Benin et al., 1999). Pb has only recently been removed from gasoline in Mexico, so soils containing Pb derived from exhaust place agricultural workers at risk of exposure. Pb is also found in traditional home remedies used in Mexico, in candies and other food products produced there, and in ceramics (Courtney et al., 2002; Lopez-Carrillo et al., 1996). As is known to be concentrated in drinking water in numerous areas of Mexico (Cebrián et al., 1994), sometimes well in excess of international standards (Méndez-Gómez et al., 2008). As is produced in Pb smelting. It has been used extensively in agricultural pesticides, contaminating soils and plants grown in them. Exposure to Hg results from eating contaminated seafood, as well as from some cultural and religious practices that include injecting mercury (Mahaffey et al., 2004; Mahaffey, 2005; Riley et al., 2001; Prasad, 2004). Cd is found in soils where certain fertilizers have been used, and in plants grown in such soils (Satarug et al., 2003). Smoking tobacco is a major source of both As and Cd exposure from the plant's absorption of these metals in the soil and from fertilizers (Satarug and Moore, 2004).

The last national estimate places the number of farmworkers and their dependents at over 4 million (HRSA, 1990); this is supported by more recent enumeration profiles conducted in individual states (www.ncfh.org/?pid+23 [accessed 27 Aug 2009]). Seventy-five percent of farmworkers in the US were born in Mexico, and a significant proportion return to Mexico on a regular basis (Carroll et al., 2005). In general, farmworkers have fewer occupational health protections than other industries (Arcury and Marín, 2009) and limited access to medical care (Arcury and Quandt, 2007), making them a population for which additional exposures to metals is an issue of environmental and occupational justice.

The aim of this study is to report data from migrant and seasonal farmworkers on urinary levels of 4 metals—As, Pb, Hg, and Cd—that have been linked to negative health consequences in humans and for which recent national reference data are available. The objectives of the paper are (1) to describe the levels of these chemicals in urine samples obtained from Latino farmworkers in eastern North Carolina, (2) explore the association of urinary chemical levels with personal and work-related characteristics, and (3) suggest areas for more focused study of these chemicals among farmworkers.

Materials and methods

Data were collected as part of a larger study of pesticide exposure. Data collection was completed in 11 counties with large migrant and seasonal farmworker populations: Bladen, Columbus, Edgecombe, Greene, Harnett, Johnston, Lenoir, Pitt, Sampson, Wayne, and Wilson Counties. Conservative estimates for 2007 by the North Carolina Employment Security Commission put the number of migrant farmworkers in these counties without H2A visas at 13,675 (36.2% of the 37,610 in North Carolina), the number of migrant farmworkers with H2A visas at 2995 (34.3% of 8730), and the number of seasonal farmworkers at 5800 (22.8% of 25,407). The major hand-cultivated and hand-harvested crops in these counties are tobacco, sweet potatoes, and cucumbers.

Sample: A two-stage procedure was used to select farmworkers. First, three local agencies that provide health and social services to farmworkers prepared a list of farmworker residential sites or camps in the counties they served. Camps were approached in order until each agency recruited an assigned number of camps and a specified number of participants. All camps that were approached agreed to participate. Second, participants in each of the camps were recruited to participate. In camps with seven or fewer residents, all farmworkers were invited to participate. In camps with more than seven residents, eight to ten farmworkers were recruited with interviewers recruiting participants as they became available. The final sample consisted of 288 workers recruited at 41 camps. For this analysis, workers not born in Mexico ($n=15$) and for whom metals data were not collected ($n=15$) were not included, producing a final sample size of 258.

Data collection: Data collection relevant to this analysis included a detailed interview and a first morning urine void to measure metals. Participants were given an incentive valued at $20. Data used in this analysis were collected from May to June 2007. Data collectors included eight fluent Spanish speakers. All of the interviewers completed an intensive course of training that included a thorough review of camp and participant selection, recruitment procedures, and data collection procedures. Particular attention was directed toward the protection of human subjects, obtaining informed consent, and maintaining confidentiality. Interviewers were trained in safe procedures for the collection and handling of biological samples. Each team of interviewers was accompanied by a supervisor to help ensure that data collection procedures were properly followed.

A detailed interview was completed with the farmworker participants. The questionnaire included items on participant personal characteristics (e.g., age, educational attainment, place of origin), work experience in US and home country agriculture, current health status, and smoking history. Based on previous data collection in this population (Spangler et al., 2003), which showed very low frequency of tobacco use in any other form, questions were restricted to cigarettes. The questionnaire was developed in English and translated by an experienced translator who was a native Spanish speaker familiar with Mexican Spanish. The translated questionnaire was reviewed by four fluent Spanish speakers familiar with farm work. The questionnaire was then pre-tested with 16 Spanish-speaking farmworkers and revised as needed.

At the end of each interview the interviewer gave the participants urine collection containers with labels attached. The urine collection and storage containers were provided by the Centers for Disease Control and Prevention and were certified to be free of metals. Participants were instructed to fill the containers with their first void upon rising the next morning. They were assured that the urine samples would be tested for agricultural chemicals and metals only, and not for the use of alcohol, drugs, or any health conditions. They were asked specifically to only provide their urine in the containers, not that of any other workers in the camp. They were asked specifically not to put any other fluid in the urine containers (e.g., water). Finally, they were asked specifically not to put any other substances in the urine containers. The participants from each camp placed their urine containers in a cooler with blue ice that was provided to them. Each morning a project interviewer stopped by the camp interviewed the previous evening and retrieved the containers, transported them to the nearest of the three collaborating community partners, transferred the samples into labeled containers, and placed the samples in a laboratory freezer where they were stored at $-20\,^{\circ}C$.

Laboratory analysis: All laboratory analyses were carried out by RTI International in Research Triangle Park, North Carolina. Sample digestion was carried out using a *Digi*PreP MS (SCP Science, Champlain, NY). Both an Analog Vortex Mixer (VWR, Suwanee, GA) and a Vortex Genie (Fischer Scientific, Pittsburgh, PA) were used for mixing the urine samples. A quadrupole ICP-MS X Series II X0637 (Thermo, Waltham, MA) was employed for the determination of the trace metals in urine. This instrument was equipped with a collision cell to mitigate the impact of polyatomic interferences. A low-volume impact bead spray chamber and Xt cones from the instrument manufacturer were used for all analyses.

Ultrex HNO_3 and Ultrex 30% H_2O_2 (JT Baker, Phillipsburg, NJ) were used in the creation of standards and samples. All metals for internal standards and for calibration standards were National Institute of Standards and Technology (NIST)-

traceable (High-Purity Standards, Charleston, SC). A standard reference material (SRM 2760) (Toxic metals in Freeze-dried Urine) was obtained from NIST (Gaithersburg, MD). Distilled de-ionized (DDI) H_2O (18 MΩ, Pure Water Solutions) was used for all sample and standard preparations.

Standard solutions for the calibration curve included all the analytes and their internal standards. Bismuth at 209 m/z was used as the internal standard for Pb and Hg. Cd's internal standard was ^{89}Y. For As, which was analyzed with the collision cell, ^{141}Pr was the internal standard. All internal standards were prepared in one solution, at 1 ppm each, with 2% HNO_3. The ICP-MS rinse solution contained 5% (v/v) HNO_3 and 10 μg/mL Au.

The urine samples were thawed, and then vortexed for 10–15 s to ensure homogeneity. Two mL of each sample were aliquoted into a digestion tube, and HNO_3 (1.00 mL), 1000 μg/mL Au (0.050 mL), and H_2O_2 (0.250 mL) were added. The samples were then digested by the *Digi*PreP MS heating block using the following sequence: ramp from room temperature to 60 °C for 30 min, hold at 60 °C for 30 min, ramp to 80 °C for 10 min, hold at 80 °C for 50 min, ramp to 110 °C for 20 min, hold at 110 °C for 100 min.

The digestion step decreased salt and organic interferences in the urine matrix. While simple dilutions (Townsend et al., 1998; Goullé et al., 2005; De Boer et al., 1998) have been successfully employed for ICP-MS preparation, the acid digestion helped improve sample throughput by reducing deposits on the ICP-MS cones. After digestion was complete, the samples were brought up to a volume of 10.0 mL with DDI H_2O and then vortexed again. IS solution (0.050 mL) was added to 5.00 mL of the digested samples, and solutions were vortexed before ICP-MS analysis.

Limits of detection (LOD) were: 0.029 μg/L for As, 0.0001 μg/L for Cd, 0.014 μg/L for Hg, and 0.0001 μg/L for Pb.

Measures: Age was categorized as 18–24, 25–29, 30–39, and 40 or more years. Current smoker was dichotomized as yes or no, based on a question asking if a worker had smoked any cigarettes in the past month. Smoking was converted to pack years. Pack years were derived from the average number of packs per day reported, multiplied by the number of years smoked. For current smokers, additional data were available concerning the number of days per month the worker currently smoked. These data were incorporated into the pack year estimate for current smokers. Pack years were divided into ordered categories: <1 pack year, 1–5 pack years, and >5 pack years. Region of birth in Mexico was categorized using state of birth as Northern (Baja California, Baja California Sur, Chihuahua, Coahuila, Nuevo Leon, Sonora, Tamaulipas, and Durango), Southern (Campeche, Chiapas, Quintana Roo, Tabasco, and Yucatan), and Central (remaining states and the Federal District). Years worked in US agriculture was categorized as 1 or less, 2–3, 4–7, and 8 or more years.

Statistical analysis: Descriptive statistics were examined for all farmworkers in the sample that originated from Mexico and for whom metals data were available. Farmworker characteristics of interest (age, sex, region from Mexico, current smoker, pack years, agriculture in home country, and years worked in US agriculture) were categorized into groups and frequency distributions reported.

Seventeen values for Hg were less than the LOD. These were imputed as LOD/sqrt(2) (Homung and Reed, 1990). To adjust for the potential effect of dehydration, all the outcome measures are defined as microgram of metals per gram of creatinine. All metals data had skewed distributions; therefore log transformations were used to normalize the data in order to conduct statistical analyses. Furthermore, all data analyses accounted for the study's clustered design. Urinary metals data from the 2003–2004 National Health and Nutrition Examination Survey (NHANES) were used as reference data. As such, these NHANES data were used only to categorize the study data from farmworkers; the NHANES were not in any way meant to be baseline or optimal values. Rather, they were intended to indicate the levels of metals typical of US residents. The NHANES reference data were restricted to persons 18 years and older. Geometric means and confidence intervals for the comparison of NHANES data and the North Carolina farmworker sample were obtained using SAS callable SUDAAN (RTI International, Research Triangle Park, NC). Statistical tests were also conducted for each metal of interest to describe the associations between the metal concentrations and farmworker characteristics. A multivariate regression model was fitted for each continuous, log-transformed metal using PROC MIXED. The models incorporated farmworker characteristics of interest including age, years worked in US agriculture, current smoking status (yes/no), region of Mexico, and pack years. The least square means and confidence intervals are reported after back-transformations. These data analyses were performed using SAS 9.1 (SAS Institute, Cary, NC) and *p*-values of less than 0.05 were considered statistically significant.

Table 1
Personal characteristics of Mexican farmworkers in eastern North Carolina, 2007 (N=258).

Personal characteristics	*N*	%
Sex		
Male	237	91.9
Female	21	8.1
Age (years)		
18–24	54	20.9
25–29	50	19.4
30–39	86	33.3
40+	68	26.4
Region of Mexico		
North	36	14
Central	194	75.2
South	28	10.9
Years worked in US agriculture		
≤ 1	43	16.7
2–3	42	16.3
4–7	75	29.1
≥ 8	95	36.8
Missing	3	1.2
Ever work in agriculture in home country		
Yes	197	76.4
No	61	23.6
Current smoker		
Yes	80	31.0
No	178	69.0
Smoking, pack years		
<1	205	79.5
1–5	30	11.6
>5	23	8.9

Results

Farmworker characteristics: Over 90% of the sample was male (Table 1). Age ranged from 18 to 73 years. About 40% of the workers were less than 30 years of age. Three-quarters were from the central region of Mexico. One third of the sample had worked 3 years or less in agriculture in the US. Most (76%) had worked in agriculture in Mexico. Most of the sample (79.5%) reported less than 1 pack year of smoking. Thirty-one percent were current smokers.

Urinary metals: The geometric means of the urinary concentrations of chemicals from Mexican farmworkers exceeded the NHANES references values for As (13.23 μg/g creatinine [95% CI 11.11, 15.35] vs. 8.55 μg/g [95% CI 7.23, 9.86]) and Pb (1.26 μg/g [95% CI 1.08, 1.43] vs. 0.63 μg/g [95% CI 0.60, 0.66]). Geometric means do not differ for Hg (0.43 μg/g [95% CI 0.31, 0.55] vs. 0.50 μg/g [95% CI 0.45, 0.55]). Farmworkers are lower than the reference values for Cd (0.20 μg/g [95% CI 0.18, 0.21] vs. 0.26 μg/g [95% CI 0.25, 0.27]). Farmworker values exceeded NHANES for the 25th, 50th, and 75th percentiles for As and for Pb (Table 2).

Predictors of urinary metals: Table 3 presents the means and confidence intervals for co-variates in each regression. Pack years of cigarettes remains significantly ($p<0.01$) associated with As levels, with mean levels of the metal increasing from 10.92 μg/g (95% CI 9.28, 12.86) for those reporting less than 1 pack year to 23.95 μg/g (95% CI 16.31, 35.16) for those reporting more than 5 pack years. Pb levels increase significantly with age (p=0.015). They are also associated with birth region in Mexico. Pb levels for the central region are significantly higher ($p<0.01$)(1.34 μg/g [95% CI 1.14, 1.59]) than those for the northern (0.91 μg/g [95% CI 0.68, 1.20]) or southern regions (0.81 μg/g [95% CI 0.59, 1.12]). Birth region in Mexico is also associated with Hg levels. Levels are higher for those born in the central (0.64 μg/g [95% CI 0.45, 0.91]) and northern regions (0.54 μg/g [95% CI 0.30, 0.97]), and significantly lower in the southern region (0.13 μg/g [95% CI 0.07, 0.25]). Both age and pack years are significantly associated with Cd ($p<0.01$ and $p<0.01$, respectively), with Cd levels increasing with both age and pack years.

Please cite this article as: Quandt, S.A., et al., Heavy metals exposures among Mexican farmworkers in eastern North Carolina. Environ. Res. (2009), doi:10.1016/j.envres.2009.09.007

Table 2
Comparison of geometric means and selected percentiles of urinary concentrations of metals (in µg/g of Creatinine) for the US population (NHANES 2003–2004) and farmworkers in North Carolina, 2007.

	Sample size	Geometric mean (95% CI)	Selected percentile (95% confidence interval)			
			25th	50th	75th	99th
Total arsenic						
NHANES	1732	8.55 (7.23, 9.86)	4.26 (3.67, 4.82)	7.37 (6.12, 8.88)	15.15 (12.23, 18.11)	160.60 (140.10, 266.38)
NC farmworkers	258	13.23 (11.11, 15.35)	7.75 (6.92, 8.69)	10.73 (9.76, 12.83)	18.98 (14.72, 26.96)	158.65 (NA)
Lead						
NHANES	1733	0.63 (0.60, 0.66)	0.40 (0.38, 0.43)	0.62 (0.59, 0.66)	0.96 (0.91, 1.02)	3.02 (2.86, 3.76)
NC farmworkers	258	1.26 (1.08, 1.43)	0.81(0.74, 0.90)	1.13 (0.99, 1.28)	1.84 (1.56, 2.21)	8.61 (NA)
Mercury						
NHANES	1716	0.50 (0.45, 0.55)	0.25 (0.21, 0.29)	0.52 (0.45, 0.59)	0.98 (0.84, 1.09)	4.82 (4.37, 9.90)
NC farmworkers	258	0.43 (0.31, 0.55)	0.24 (0.16, 0.30)	0.56 (0.42, 0.70)	1.11 (0.94, 1.46)	5.56 (NA)
Cadmium						
NHANES	1722	0.26 (0.25, 0.27)	0.14 (0.13, 0.15)	0.26 (0.24, 0.28)	0.48 (0.44, 0.52)	1.62 (1.53, 1.98)
NC farmworkers	258	0.20 (0.18, 0.21)	0.14 (0.13, 0.15)	0.18 (0.17, 0.20)	0.27 (0.23, 0.30)	0.86 (NA)

Table 3
Multivariate associations of worker characteristics with urinary concentrations of metals, farmworkers in North Carolina, 2007.

Co-variates	Metal (outcome) (µg/g creatinine)															
	Arsenic				Lead				Mercury				Cadmium			
	Mean	95% CI		*p*-value	Mean	95% CI		*p*-value	Mean	95% CI		*p*-value	Mean	95% CI		*p*-value
Age				0.20				0.015				0.75				< 0.01
18–24	14.50	10.91	19.27		0.79	0.62	1.02		0.29	0.17	0.50		0.15	0.13	0.18	
25–29	15.31	11.55	20.28		0.90	0.70	1.15		0.39	0.23	0.66		0.19	0.16	0.23	
30–39	19.10	14.98	24.36		1.14	0.92	1.42		0.36	0.22	0.56		0.21	0.18	0.24	
40+	18.64	14.68	23.66		1.21	0.98	1.50		0.39	0.25	0.62		0.25	0.21	0.29	
Region in Mexico				0.50				< 0.01				< 0.01				0.17
North	14.64	10.70	20.03		0.91	0.68	1.20		0.54	0.30	0.97		0.19	0.16	0.24	
Central	16.90	14.06	20.32		1.34	1.14	1.59		0.64	0.45	0.91		0.22	0.19	0.25	
South	19.05	13.33	27.24		0.81	0.59	1.12		0.13	0.07	0.25		0.18	0.14	0.23	
Pack-years				< 0.01				0.99				0.30				< 0.01
< 1	10.92	9.28	12.86		1.00	0.87	1.16		0.27	0.20	0.36		0.17	0.15	0.19	
1–5	18.02	13.21	24.57		1.00	0.76	1.33		0.37	0.21	0.67		0.16	0.13	0.20	
> 5	23.95	16.31	35.16		0.98	0.69	1.38		0.45	0.22	0.92		0.28	0.21	0.35	
Current smoker				0.30				0.27				0.70				0.39
Yes	15.73	12.76	19.38		1.06	0.88	1.28		0.34	0.23	0.50		0.20	0.18	0.23	
No	17.88	14.08	22.69		0.94	0.76	1.16		0.37	0.24	0.58		0.19	0.16	0.22	
Years in US agriculture				0.38				0.28				0.38				0.31
≤ 1	16.03	12.12	21.21		0.86	0.67	1.10		0.34	0.20	0.57		0.18	0.15	0.22	
2–3	15.29	11.42	20.47		0.95	0.73	1.23		0.40	0.23	0.70		0.19	0.16	0.23	
4–7	19.55	15.24	25.09		1.12	0.90	1.40		0.42	0.26	0.66		0.22	0.18	0.26	
≥ 8	16.48	12.81	21.21		1.08	0.86	1.36		0.28	0.17	0.45		0.20	0.17	0.24	

Discussion

This study compares creatinine-adjusted urine levels of metals among North Carolina farmworkers with the general US population and examines their associations with a series of relevant personal and occupational characteristics. Farmworkers exceed the US population in levels of As and Pb, are similar for Hg, and are lower in Cd.

For most populations, As exposure occurs from ingestion of As-containing drinking water or food. Levels of As in groundwater are naturally high in some places. Hydrothermal activity in active volcanic areas can increase As content of groundwater, as can human activities including production of non-ferrous alloys, metal production and agricultural applications of pesticides. As groundwater is tapped for wells, population exposure increases. Several areas of Mexico have been investigated for their high levels of As in groundwater. This includes the trans-Mexican Volcanic Belt, a 500 km wide belt cutting across central Mexico (Hurtado-Jiménez and Gardea-Torresdey, 2006), as well as several areas in northern Mexico (Cebrián et al., 1983; Méndez-Gómez et al., 2008; Meza et al., 2004). Because As is fairly widespread in groundwater (National Research Council, 1999), it is not surprising that birth region of Mexico is not associated with As levels in farmworkers. There is increasing concern about As in groundwater in North Carolina, based on data from geological studies (Bradley et al., 2008) and private well assessment. While much of the concern centers on areas of the state west of the areas where the farmworkers in the current study work and reside, some detection of elevated As occurs in wells in the study area. Further study of local water sources, as well as farmworker patterns of water consumption (e.g., bottled water vs. private well water) is necessary to evaluate exposures in North Carolina.

Pb and Hg are both associated with birth region of Mexico, with the lowest values found in those from the south of the country and highest, the central area. This may reflect the greater proportion of ore smelters located in the central and northern regions, as well as greater population density and industry. The state of Coahuila, which borders Texas, for example, contains the largest non-ferrous metal processing site in Latin America and the fourth largest in the world (Benin et al., 1999; Calderón-Salinas et al., 1996), with dust samples taken in residential areas showing levels of Pb in excess of Superfund clean-up goals. Hg is also released in metal smelting. Pb in soil in Mexico might also reflects the historical use of lead arsenate there, though its use was widespread and cannot be traced to specific regions (González-Farias, 2003).

Cd and As among these farmworkers are both related to pack years of cigarette smoking. This is not unexpected, as both chemicals are present in the soils in which tobacco is grown, either occurring naturally or from insecticides such as lead arsenate (which was used historically throughout the US including North Carolina and remains in the soil [Hood, 2006]) or fertilizers. Tobacco from the US has been found to have relatively high levels of As, compared to tobacco from elsewhere in the world (Lugon-Moulin et al., 2008). Cigarette smoking is practiced at low intensity in the farmworker population. Farmworkers who smoke report smoking, on average, less than 5 cigarettes per day (Spangler et al., 2003), with younger smokers reporting fewer cigarettes smoked per day than older smokers. This age-related difference likely accounts for current smoking status not predicting metals exposure, but pack years, predicting both As and Cd.

The farmworker population shows exposure to multiple metals that share common mechanisms that underlie their toxic actions (Wang and Fowler, 2008). Although metals are commonly encountered as mixtures in the environment, most research has assessed exposure and outcomes separately. Recent work by ATSDR (2007b) has constructed interaction profiles of some combinations of metals, showing that the joint toxic action in some cases is greater than additive for the nervous system and other endpoints. Farmworkers are also exposed to pesticides, including organophosphorus pesticides, organochlorines, carbamates, and pyrethroids, which have been linked to neurotoxic effects in farmworkers (Kamel et al., 2003; Alavanja et al., 2004; Rohlman et al., 2007). The interaction effects of these pesticides with each other, as well as with metals, are unknown. Existing research (e.g., Uversky et al., 2002) suggests that they may be additive, synergistic or produce new effects not seen in exposure to single compounds.

This study demonstrates elevated urine levels for some metals in the North Carolina migrant worker population. The source of the farmworkers' exposure to these metals is not clear. However, the multivariate analysis suggests that it is likely that these farmworkers have been exposed to them in their communities of origin, rather than occupationally in the US.

The findings reported here should be interpreted in light of the study's limitations. Data were collected from farmworkers only in North Carolina. Therefore, the sample may not represent all farmworkers in the US. The cross-sectional study design prevents making conclusions concerning causality between farmworker experiences and metals data. No data on possible health outcomes from metals exposure are available. Additional data on other local sources of metals (e.g., diet and groundwater in North Carolina) would be helpful in interpreting the findings. Finally, consideration of the differences among these metals in half-life and the extent to which recent intakes and body burden are reflected in urinary measures should be considered.

Nevertheless, this study uses a large sample chosen to be representative of farmworkers in the study area. It is the first study to examine the levels of urinary metals in farmworkers in the US. The research findings suggest that farmworkers have a greater body burden of metals than the general US population. Their exposure to agricultural pesticides, many of which are also neurotoxins, suggests that they may be at an elevated risk for adverse health effects from their combined occupation and environmental exposures.

Funding

This research was supported by grant R01 ES008739 from the National Institute of Environmental Health Sciences and by a grant from the Wake Forest University Cross-Campus Collaborative Research Support Fund.

Human subjects approval

This research, including the procedure for obtaining informed consent, was approved by the Wake Forest University School of Medicine Institutional Review Board.

References

Alavanja, M.C., Hoppin, J.A., Kamel, F., 2004. Health effects of chronic pesticide exposure: cancer and neurotoxicity. Annu. Rev. Public Health 25, 155–197.

Arcury, T.A., Grzywacz, J.G., Chen, H., Vallejos, Q.M., Galván, L., Whalley, L.E., Isom, S., Barr, D.B., Quandt, S.A., 2009. Variation across the agricultural season in organophosphorus pesticide urinary metabolite levels for Latino farmworkers in eastern North Carolina: project design and descriptive results. Am. J. Ind. Med. 52 (7), 539–550.

Arcury, T.A., Marín, A.J., 2009. Latino farmworkers and farm work in the eastern United States: the context for health, safety, and justice. In: Arcury, T.A., Quandt, S.A. (Eds.), Latino Farmworkers in the Eastern United States: Health, Safety and Justice. Springer, New York, pp. 15–36.

Arcury, T.A., Quandt, S.A., 2007. Delivery of health services to migrant and seasonal farmworkers. Ann. Rev. Public Health 28, 345–363.

ATSDR, 2006. Arsenic. Chemical Agent Briefing Sheet. Available: http://www.atsdr.cdc.gov/cabs/arsenic/index.html#effect [Accessed, 1-29-09].

ATSDR, 2007a. 2007 CERCLA Priority List of Hazardous Substances. Available: http://www.atsdr.cdc.gov/cercla/07list.html, [Accessed, 2-3-09].

ATSDR, 2007b. Interaction Profiles for Toxic Substances, Available: http://www.atsdr.cdc.gov/interactionprofiles/ [Accessed, 2-10-09].

ATSDR, 2007c. Public Health Statement. Arsenic. Available http://www.atsdr.cdc.gov/toxprofiles/phs2.html, [Accessed, 8-31-09].

ATSDR, 2008. Public Health Statement. Cadmium. Available http://www.atsdr.cdc.gov/toxprofiles/phs5.html [Accessed, 8-31-09].

ATSDR, 2007d. Public Health Statement. Lead. Available: http://www.atsdr.cdc.gov/toxprofiles/phs13.html#bookmark04 [Accessed, 8-31-09].

ATSDR, 1999. Public Health Statement. Mercury. Available: http://www.atsdr.cdc.gov/toxprofiles/phs46.html [Accessed, 8-31-09].

Benin, A.L., Sargent, J.D., Dalton, M., Roda, S., 1999. High concentrations of heavy metals in neighborhoods near ore smelters in northern Mexico. Environ. Health Perspect. 107, 279–284.

Bradley, P.J., Kim, D., Tootoo, J., 2008. Geological aspects of naturally occuurring arsenic in groundwater in the Chapel Hill, Hillsborough and Efland 7.5-minute quadrangles, Carolina Terrane, North Carolina. Geol. Soc. Am. Abstr. Programs 40 (4), 53.

Calderón, J., Navarro, M.E., Jimenez-Capdeville, M.E., Santos-Diaz, M.A., Golden, A., Rodriguez-Leyva, I., Borja-Aburto, V., Díaz-Barriga, F., 2001. Exposure to arsenic and lead and neuropsychological development in Mexican children. Environ. Res. 85 (2), 69–76.

Calderón-Salinas, J.V., Valdéz-Anaya, B., Mazúñiga-Charles, Albores-Medina, A., 1996. Lead exposure in a population of Mexican children. Hum. Exp. Toxicol. 15 (4), 305–311.

Carroll, D., Samardick, R.M., Bernard, S., Gabbard, S., Hernandez, T., 2005. Findings from the National Agricultural Workers Survey (NAWS) 2001–2002. Research Report No. 9. U.S. Department of Labor, Washington, DC.

Cebrián, M.E., Albores, A., Aguilar, M., Blakely, E., 1983. Chronic arsenic poisoning in the north of Mexico. Hum. Toxicol. 2, 121–133.

Cebrián, M.E., Albores-Medina, A., García-Vargas, G.G., Del Razo, G., 1994. Chronic arsenic poisoning in humans. The case of Mexico. In: Niriagu, J.O. (Ed.), Arsenic in the Environment. Part II: Human Health and Ecosystem Effects. John Wiley & Sons, New York, pp. 93–107.

Courtney, J.E., Ash, S., Kilpatrick, N., Buchanan, S., Meyer, P., Kim, D., Brown, L., 2002. Childhood lead poisoning associated with tamarind candy and folk remedies—California, 1999–2000. Morb. Mortal. Wkly. Rep. 51 (31), 684–686.
De Boer, J.L.M., de Joode, P., Ritsema, R., 1998. Direct inductively coupled plasma mass spectrometric determination of cadmium in urine with special attention to matrix effect correlation. J. Anal. At. Spectrosc. 13, 971–975.
González-Farias, 2003. In: Taylor, M.D., Klaine, S.J., Carvalho, F.P., Barcelo, D., Everaarts, J. (Eds.), Pesticide Residues in Coastal Tropical Ecosystems: Distributions, Fate and Effects. Taylor & Francis, London and New York, pp. 311–337.
Goullé, J.-P., Mahieu, L., Castermant, J., Neveu, N., Bonneau, L., Lainé, G., Bouige, D., Lacroix, C., 2005. Metal and metalloid multi-elementary ICP-MS validation in whole blood, plasma, urine and hair: reference values. Forensic Sci. Int. 153 (1), 39–44.
Goyer, R.A., Liu, J., Waalkes, M.P., 2004. Cadmium and cancer of prostate and testis. Biometals 17, 555–558.
HRSA, 1990. An atlas of state profiles which estimates number of migrant and seasonal farmworkers and members of their families. Health Resources and Services Administration, Washington, DC.
Homung, R.W., Reed, D.L., 1990. Estimation of average concentration in the presence of nondetectable values. Appl. Occup. Environ. Hyg. 5, 46–51.
Hood, E., 2006. The apple bites back: claiming old orchards for residential development. Environ. Health Perspect. 114 (8), A471–A476.
Hurtado-Jiménez, R., Gardea-Torresdey, J.L., 2006. Arsenic in drinking water in the Los Altos de Jalisco region of Mexico. Rev. Panam. Salud Publica 20 (4), 236–247.
Hu, H., 2002. Human health and heavy metals exposure. In: McCally, M. (Ed.), Life Support: The Environment and Human Health. MIT Press, Cambridge, pp. 65–82.
Il'yasova, D., Schwartz, G.G., 2005. Cadmium and renal cancer. Toxicol. Appl. Pharmacol. 207 (2), 179–186.
Kamel, F., Rowland, A.S., Park, L.P., Anger, W.K., Baird, D.D., Gladen, B.C., Moreno, T., Stallone, L., Sandler, D.P., 2003. Neurobehavioral performance and work experience in Florida farmworkers. Environ. Health Perspect. 111 (14), 1765–1772.
Lampe, B.J., Park, S.K., Robins, T., Mukherjee, B., Litonjua, A.A., Amarasiriwardena, C., Weisskopf, M., Sparrow, D., Hu, H., 2008. Association between 24-hour urinary cadmium and pulmonary function among community-exposed men: the VA Normative Aging Study. Environ. Health Perspect. 116 (9), 1226–1230.
Lopez-Carrillo, L., Torres-Sanchez, L., Garrido, F., Papaqui-Hernandez, J., Palazuelos-Rendon, E., Lopez-Cervantes, M., 1996. Prevalence and determinants of lead intoxication in Mexican children of low socioeconomic status. Environ. Health Perspect. 104, 1208–1211.
Lugon-Moulin, N., Martin, F., Krauss, M.R., Ramey, P.R., Rossi, L., 2008. Arsenic concentration in tobacco leaves: a study on three commercially important tobacco (*Nicotiana tabacum* L.) types. Water Air Soil Pollut. 192, 315–319.
Mahaffey, K.R., Clickner, R.P., Bodurow, C.C., 2004. Blood organic mercury and dietary mercury intake: National Health and Nutrition Examination Survey, 1999 and 2000. Environ. Health Perspect. 112 (5), 562–570.
Mahaffey, K.R., 2005. Mercury exposure: medical and public health issues. Trans. Am. Clin. Climatol. Assoc. 116, 127–153.
Méndez-Gómez, J., García-Vargas, G.G., López-Carrillo, L., Calderón-Aranda, E.S., Gómez, A., Vera, E., Valverde, M., Cebrián, M.E., Rojas, E., 2008. Genotoxic effects of environmental exposure to arsenic and lead on children in region Lagunera, Mexico. Ann. N. Y. Acad. Sci. 1140, 358–367.
Menke, A., Muntner, P., Silbergeld, E.K., Platz, E.A., Guallar, E., 2009. Cadmium levels in urine and mortality among US adults. Environ. Health Perspect. 117 (2), 190–196.
Meza, M.M., Kopplin, M.J., Burgess, J.L., Gandolfi, A.J., 2004. Arsenic drinking water exposure and urinary excretion among adults in the Yaqui Valley, Sonora, Mexico. Environ. Res. 96, 119–126.
National Research Council, 1999. Subcommittee on Arsenic in Drinking Water, Arsenic in Drinking Water. National Academy Press, Washington, DC.
Navas-Acien, A., Silbergeld, E.K., Pastor-Barriuso, R., Guallar, E., 2008. Arsenic exposure and prevalence of type 2 diabetes in US adults. JAMA 300 (7), 814–822.
Prasad, V., 2004. Subcutaneous injection of mercury: "warding off evil". Environ. Health Perspect. 112 (13), 1326–1328.
Riley, D.M., Newby, C.A., Leal-Almeraz, T.O., Thomas, V.M., 2001. Assessing elemental mercury vapor exposure from cultural and religious practices. Environ. Health Perspect. 109 (8), 779–784.
Rohlman, D.S., Lasarev, M., Anger, W.K., Scherer, J., Stupfel, J., McCauley, L., 2007. Neurobehavioral performance of adult and adolescent agricultural workers. Neurotoxicology 28 (2), 374–380.
Satarug, S., Baker, J.R., Urbenjapol, S., Haswell-Elkins, M., Reilly, P.E., Williams, D.J., Moore, M.R., 2003. A global perspective on cadmium pollution and toxicity in non-occupationally exposed population. Toxicol. Lett. 137, 65–83.
Satarug, S., Moore, M.R., 2004. Adverse health effects of chronic exposure to low-level cadmium in foodstuffs and cigarette smoke. Environ. Health Perspect. 112 (10), 1099–1103.
Shih, R.A., Hu, H., Weisskopf, M.G., Schwartz, B.S., 2007. Cumulative lead dose and cognitive function in adults: a review of studies that measured both blood lead and bone lead. Environ. Health Perspect. 115 (3), 483–492.
Spangler, J.G., Arcury, T.A., Quandt, S.A., Preisser, J.S., 2003. Tobacco use among Mexican farmworkers working in tobacco: implications for agromedicine. J. Agromed. 9 (1), 83–91.
Townsend, A.T., Miller, K.A., McLean, S., Aldous, S., 1998. The determination of copper, zinc, cadmium and lead in urine by high resolution ICP-MS. J. Anal. At. Spectrosc. 13, 1213–1219.
Tsai, S.Y., Chou, H.Y., The, H.W., Chen, C.M., Chen, C.J., 2003. The effects of chronic arsenic exposure from drinking water on the neurobehavioral development in adolescence. Neurotoxicology 24 (4–5), 747–753.
Uversky, V.N., Li, J., Bower, K., Fink, A.L., 2002. Synergistic effects of pesticides and metals on the fibrillation of α-synuclein: implications of Parkinson's disease. Neurotoxicology 23, 527–536.
Wang, G., Fowler, B.A., 2008. Roles of biomarkers in evaluating interactions among mixtures of lead, cadmium and arsenic. Toxicol. Appl. Pharmacol. 233 (1), 92–99.
Wasserman, G.A., Liu, X., Parvez, F., Ahsan, H., Factor-Litvak, P., van Geen, A., Slavkovich, V., LoIacono, N.J., Cheng, Z., Hussain, I., Momotaj, H., Graziano, J.H., 2004. Water arsenic exposure and children's intellectual function in Araihazar, Bangladesh. Environ. Health Perspect. 112 (13), 1329–1333.
Wild, P., Bourgkard, E., Parism, C., 2009. Lung cancer and exposure to metals: the epidemiological evidence. In: Verma, N. (Ed.), Methods of Molecular Biology, Cancer Epidemiology, vol. 472. Humana Press, Totowa, NJ, pp. 139–167.

Please cite this article as: Quandt, S.A., et al., Heavy metals exposures among Mexican farmworkers in eastern North Carolina. Environ. Res. (2009), doi:10.1016/j.envres.2009.09.007