Organophosphorus Pesticide Urinary Metabolite Levels of Children in Farmworker Households in Eastern North Carolina

Thomas A. Arcury,[1]* Joseph G. Grzywacz,[1] Stephen W. Davis,[1] Dana B. Barr,[2] and Sara A. Quandt[3]

Background *Organophosphorus (OP) pesticide urinary metabolite levels in a sample of farmworker children in North Carolina are documented and compared to national reference data. The relative importance of para-occupational, residential, and environment risk factors are delineated.*

Methods *Urine samples were collected from 60 farmworker children 1–6 years of age, and interviews were completed by their mothers. Urine samples were analyzed for the dialkylphosphate (DAP) metabolites of OP pesticides. Summed molar concentrations of the diethyl and dimethyl DAP metabolites provided summary measures.*

Results *The farmworker children had relatively high levels of OP pesticide urinary metabolites compared to national reference data; for example, participating children had higher geometric means for diethylphosphate (DEP), diethylthiophosphate (DETP), and the summed diethyl metabolites. However, analyses found no pattern of significant associations between predictors and metabolite levels.*

Conclusions *Future research requires greater precision in sampling and measurement to determine the risk factors for pesticide exposure among farmworker children.* Am. J. Ind. Med. 49:751–760, 2006. *© 2006 Wiley-Liss, Inc.*

KEY WORDS: child health; farmworker; health disparities; agriculture; occupational health; pesticide exposure; biomonitoring; organophosphorus pesticide metabolites

[1]Department of Family and Community Medicine, Wake Forest University School of Medicine, Winston-Salem, North Carolina
[2]National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia
[3]Department of Epidemiology and Prevention, Division of Public Health Sciences, Wake Forest University School of Medicine, Winston-Salem, North Carolina
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*Correspondence to: Thomas A. Arcury, Department of Family and Community Medicine, Wake Forest University School of Medicine, Medical Center Boulevard, Winston-Salem, NC 27157-1084. E-mail: tarcury@wfubmc.edu

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INTRODUCTION

Farmworkers are employed in one of the most hazardous industries, they are paid very low wages, seldom have health benefits, and, due to recent immigration or the lack of documentation, have limited access to health services [Arcury and Quandt, 2007]. Farmworkers and their family members have high rates of occupational and environmental injuries and illness [Villarejo, 2003]. Pesticides are one class of chemicals to which farmworkers maybe occupationally and environmentally exposed.

Organophosphorus (OP) insecticides are among the most widely used pesticides. OP pesticides commonly used in North Carolina agriculture include acephate, azinphos methyl, chlorpyrifos, diazinon, dimethoate, disulfoton, and phosmet. Exposure to OP pesticides is detrimental to human health [Reigart and Roberts, 1999]. Immediate effects of limited OP pesticide exposure include rash, nausea, vomiting, and blurry vision. Immediate effects of significant exposure include disorientation, loss of continence, coma, and death. Delayed effects of limited or significant exposure may include sterility, birth defects, neurodegenerative disease, and cancer [Reigart and Roberts, 1999].

OP pesticide exposure among migrant and seasonal farmworkers, and their resident children is a growing concern and is considered an issue of environmental injustice. Farmworkers have little or no control of their exposure [Austin et al., 2001]. Workers seldom have access to facilities at work that allow them to change out of work clothes and shower before coming home [GAO, 2000; Arcury et al., 2001]. The housing available to farmworkers is often located near fields to which pesticides are applied [HAC, 2001; Early et al., 2006]. Farmworkers and their spouses are often not provided with the information they need to protect themselves and their families from exposure [Arcury et al., 1999; Rao et al., 2006].

The literature examining pesticide exposure among children who live in farmworker households is limited but growing. Several studies have measured the environmental exposure of these children using dust samples collected in farmworker homes [e.g., Simcox et al., 1995; McCauley et al., 2003; Quandt et al., 2004]. Other studies have measured the levels of OP pesticide metabolites in urine samples from children living in farmworker households. Projects have been conducted in Washington [Loewenherz et al., 1997; Fenske et al., 2000a, 2002; Curl et al., 2002; Koch et al., 2002; Thompson et al., 2003; Coronado et al., 2004], Oregon [Lambert et al., 2005], California [Bradman et al., 2005; Mills and Zahm, 2001], the Rio Grande Valley of Texas [Shalat et al., 2003], and North Carolina [Arcury et al., 2005]. While these studies differ methodologically, together they have begun to report a consistent story of pesticide exposure among children who live in farmworker households.

Systematic Model of Pesticide Exposure

A model predicting pesticide exposure among the children as related to para-occupational, residential, and environmental factors has been described [Quandt et al., 2006; Fenske et al., 2000b]. Para-occupational exposure results directly from contact with persons doing farmwork, such as direct contact with a parent or other household resident employed in farmwork. Residential exposure results from contact with agricultural pesticides in the home, as well as from the residential application of pesticides. These pesticides may accumulate from several sources, such as pesticides that are brought into the dwelling by workers on clothing, boots, or containers, as well as pesticides that are directly applied to the dwelling. Characteristics such as amount of carpeting and general repair can affect the amount of pesticides that enter and accumulate in the dwelling and cleaning will reduce the amount of agricultural pesticides that accumulate. Environmental exposure results from pesticides that are applied in the larger environment in which the child lives, such as drift during application.

The model predicts that each of these forms of exposure is moderated by safety behaviors exercised by household residents and by characteristics of the child and parents. Safety behaviors include showering immediately after work, as well as storage and laundering of soiled work clothes separate from the child's clothing. The implementation of safety behaviors is more likely if parents have received safety training. Child characteristics, such as sex and age, will modify exposure, as children of different ages and sex have different exposure behaviors (e.g., younger children with more hand-to-mouth behaviors, older children with more outside play). They also metabolize OP pesticides differently. Parental characteristics that could modify exposure behaviors include educational attainment.

Objectives

The first objective is to describe the urinary OP pesticide metabolite levels among young children living in farmworker households located in eastern North Carolina, and to compare these levels to national reference data from the 1999 to 2000 National Health and Nutrition Examination Survey (NHANES). This description includes six non-specific OP pesticide metabolite levels, as well as the sums of the three diethyl and the three dimethyl OP pesticide metabolites. The second objective is to delineate the relative importance of para-occupational, residential and environment risk factors for the urinary OP pesticide metabolite levels. This analysis is based on urine samples collected from 60 children, 1–6 years of age, living in eastern North Carolina farmworker households during the 2004 agricultural production season.

MATERIALS AND METHODS

This analysis was conducted as part of *Casa y Campo*, a 4-year effort funded by the National Institute for Occupational Safety and Health that brings together environmental health scientists, health care providers, and farmworkers to reduce pesticide exposure and adverse health effects of pesticide exposure among farmworkers and their families, and to address other health issues of concern to the farmworker community. *Casa y Campo* was implemented in a six county area of eastern North Carolina, including Duplin, Harnett, Johnston, Sampson, Wake, and Wayne counties. For 2004, the North Carolina Employment Security Commission estimated that 21,614 migrant and seasonal farmworkers (not counting dependents) worked in these counties during peak harvest, accounting for one-quarter of the 86,040 migrant and seasonal farmworkers in the state.

Sampling and Recruitment

The data for this analysis were collected as part of a larger survey of farmworker housing conditions, pesticide safety behaviors, and health services utilization conducted for *Casa y Campo* from July to August, 2004. Eligible respondents for the larger survey (n = 186) had at least one child under the age of 18 years residing in the household, and either had been employed in farm work during the previous year or were residing with another adult who had been employed in farm work during the previous year. Eligible participants for this analysis (n = 60) had at least one co-resident child aged 1–6 years. These households were asked to collect a first morning urine void from the child between 1 and 6 years of age who was closest to age 5 years. All 60 eligible households agreed to participate.

Eight project staff members used a site-based method of recruitment, recruiting respondents from Migrant Head Start centers, churches, laundromats, and other sites [Arcury and Quandt, 1999]. This sampling method is appropriate for hard to find populations, such as Latino immigrants residing in rural communities [Parrado et al., 2005]. Respondents were told they would receive a small gift, a bag of food, at the end of the study for completing the interview. Those who collected a urine sample from their child were told that they would also receive an incentive of $10. Study procedures were approved by the Wake Forest University School of Medicine and the Centers for Disease Control and Prevention's (CDC) Institutional Review Boards.

Data Collection

Questionnaire data were collected by eight staff members, who were either bilingual or native Spanish speakers. Interviewers were trained by the study investigators in participant recruitment, interview technique, interview content, the safe handling of biological materials, and ethical behavior related to study participants. All participants gave written informed consent. The interviewer-administered questionnaires were completed in the respondents' homes in their preferred language, which was Spanish in all cases. Data were collected on respondent and child characteristics, household characteristics, and dwelling quality. Interviews took approximately 25 min to complete. At the end of the interview, participants with an eligible child were asked to collect a first morning void from the child the next morning. Urine collection materials were left with participants. Each child's urine sample was picked up from the home by a project staff member the morning the sample was collected and transported in a cooler with blue ice to our field laboratory where it was frozen to $-20°C$. In seven instances, first morning voids were not collected, and the child participant provided a spot void.

Laboratory Analysis

The frozen urine samples were shipped overnight on dry ice to CDC in Atlanta, Georgia, for analysis. Samples were analyzed for the dialkylphosphate (DAP) metabolites of OP pesticides using the method of Bravo et al. [2004]. Urine samples were thawed to room temperature. A 2-ml aliquot of each sample was fortified with isotopically labeled internal standards, and then mixed. The urine samples were lyophilized overnight to remove all traces of water. The residue was dissolved in acetonitrile and diethyl ether, and the DAP metabolites were chemically derivatized to their respective chloropropyl phosphate esters. The reaction mixture was concentrated, and the phosphate esters were measured using gas chromatography-positive chemical ionization-tandem mass spectrometry in the multiple reaction monitoring mode. Unknown analyte concentrations were quantified using isotope dilution calibration with calibration plots generated with each sample run. Six analytes were measured in each sample: dimethylphosphate (DMP), dimethylthiophosphate (DMTP), dimethyldithiophosphate (DMDTP), diethylphosphate (DEP), diethylthiophosphate (DETP), and diethyldithiophosphate (DEDTP). The reported limits of detection (LOD) were 0.5 μg/L for DMP, 0.5 μg/L for DMTP, 0.2 μg/L for DMDTP, 0.2 μg/L for DEP, 0.2 μg/L for DETP, and 0.2 μg/L for DEDTP. To ensure quality data, additional quality control materials, fortified samples, and blank samples were analyzed in parallel with all unknown samples.

For each of the six OP pesticide urinary metabolites, values that were at or above the LOD were used. For samples that were below the LOD but for which a detectable amount of metabolite was measured, the detected amount was used. Samples that were below the LOD and for which no detectable amount of metabolite was measured (that were zero), were assigned the value that was equal to the LOD of that metabolite divided by the square root of two. This procedure was selected as it is the same procedure used by Barr et al. [2004] for the 1999–2000 NHANES. Using this procedure, the value 0.35 μg/L was assigned for undetected DMP (4 urine samples), 0.35 μg/L for DMTP (12 samples), 0.14 μg/L for DMDTP (13 samples), 0.14 μg/L for DEP (11 samples), 0.14 μg/L for DETP (9 samples), and 0.14 μg/L for DEDTP (50 samples). For two subjects, one for DEP and one for DMTP, a sufficient volume of urine was not available for analysis. These were considered missing data and no values were assigned. Because exploratory descriptive statistics suggested that the distributions of the individual metabolites were not normal, each metabolite was adjusted using a log normal transformation.

Summed molar concentrations of the three diethyl (DEP, DETP, DEDTP) and three dimethyl (DMP, DMTP, DMDTP) metabolites were calculated to provide summary measures of exposure that were less affected by results below the LOD for individual metabolites. The untransformed concentration (μg/L) of each metabolite in each sample was converted to its molar concentration (DMP = concentration/0.126 μg/nmol; DMTP = concentration/0.142 μg/nmol; DMDTP = concentration/0.158 μg/nmol; DEP = concentration/0.154 μg/nmol; DETP = concentration/0.170 μg/nmol; DEDTP = concentration/0.186 μg/nmol), and the three diethyl and three dimethyl metabolites were summed.

Creatinine levels varied among the samples by participant age and sex. Among the girls, mean creatinine level was 66.1 μg/L (SD 24.4) for those aged 1–2 years (n = 3), 93.2 μg/L (SD 42.5) for those aged 3–4 years (n = 18), and 92.7 μg/L (SD 32.9 for those aged 5–6 years (n = 13). For boys, mean creatinine level was 79.2 μg/L (SD 40.7) for those aged 1–2 years (n = 2), 85.0 μg/L (SD 41.2) for those aged 3–4 years (n = 18), and 106.1 μg/L (SD 42.3) for those aged 5–6 years (n = 6).

Measures

The outcome variables were based on OP pesticide metabolite concentrations obtained from each child's urine sample. Measures included the concentrations of each of the six metabolites and the summed concentrations of the three diethyl and the three dimethyl metabolites.

Measures were constructed for each of the domains of the systematic model of pesticide exposure. Measures of para-occupational exposure included the dichotomous variables whether mother was currently employed doing farm work, and whether father was currently employed doing farm work. A third para-occupational exposure measure was number of farmworkers in house, which was coded 1, 2, and 3 or more. Dwelling ownership was one residential exposure measure, and was coded own, rent, and other, where other could include having housing provided by a grower. Ease of cleaning had the self-reported values of easy or difficult. Number of bathrooms was coded one, two, or three; number of rooms with carpet had the values 0, 1–2, and 3 or more. Proximity to nearest agricultural field was the environmental exposure variable, and was coded adjacent or non-adjacent.

Measures of safety behaviors included whether the mother had pesticide safety training and whether the father had pesticide safety training; each of these measures was coded no farm work, farm work and training, farm work and no training. Whether any household resident employed doing farm work regularly delayed showering after returning home from work for more than 15 min, or regularly changed farm work clothes inside the dwelling were dichotomous measures. The storage of soiled farm work clothes was coded everyone stores clothes outside, anyone stores clothes inside, and anyone stores work clothes with other clothes. The laundering of farm work clothes was coded everyone launders farm clothes separately, or anyone launders farm clothes with other clothes.

Measures of child and parental characteristics included child sex and child age (1 or 2 years, 3 or 4 years, 5 or 6 years). Mother's education was coded primary (6 years or less in the Mexican school system), secondary (7–9 years in the Mexican school system), and greater than secondary; and mother's current employment was coded none, part time, and full time.

Data Analysis

SPSS software (SPSS Inc., Chicago, IL) was used for all analyses. Initial descriptive statistics were calculated for the individual OP pesticide metabolites and for the summed diethyl and dimethyl metabolites. These descriptive statistics were then calculated for the individual and summed metabolites by child sex and age. The means and percentiles of the six individual metabolites and the summed diethyl and dimethyl metabolites were compared to the 1999–2000 NHANES reference data.

Bivariate associations between the log transformed individual metabolites and the summed diethyl and dimethyl metabolites with predictor variables were then examined via analysis of variance (ANOVA). To ensure that creatinine levels did not affect the outcome of the statistical analyses, the same bivariate ANOVAs were then performed on creatinine adjusted, log transformed, individual, and summed metabolite levels. There were no differences between the unadjusted and creatinine adjusted results, and unadjusted results are reported.

Based on the bivariate analysis, the number of predictor variables was reduced and used in separate regression models predicting the summed diethyl and dimethyl metabolites. Only those predictor variables for which the ANOVA indicated significance of $P < 0.20$ were included. Additional analyses were then completed in which regression models were run for each individual OP pesticide metabolite with those predicator variables included for which the ANOVA indicated significance of $P < 0.20$. All regression analyses were run with creatinine unadjusted and creatinine adjusted metabolite measures. There were no differences between the unadjusted and creatinine adjusted results, and unadjusted results are reported.

RESULTS

Exposure, Safety Behavior, and Personal Characteristics

While the children considered in this analysis all lived in households that included at least one farmworker, they

TABLE I. Exposure Characteristics of Children Aged 1–6 Years Living in Farmworker Families, Eastern North Carolina, 2004

Exposure characteristics	N	%
Para-occupational exposure		
Mother does farm work	41	68.3
Father does farm work	34	56.7
Number of farmworkers in house		
1	23	38.3
2	22	36.7
3 or more	15	25.0
Residential exposure		
Dwelling ownership		
Own	20	33.3
Rent	32	53.3
Other	8	13.3
Ease of cleaning		
Easy	35	58.3
Difficult	25	41.7
Number of bathrooms		
1	32	53.3
2 or 3	28	46.7
Number of rooms with carpet		
0	5	8.3
1 or 2	14	23.4
3 or more	41	68.3
Environmental exposure		
Proximity to nearest agricultural field		
Adjacent	26	43.3
Non-adjacent	34	56.7
Safety behaviors		
Mother's pesticide safety training		
No farm work	19	31.7
Farm work and training	18	30.0
Farm work and no training	23	38.3
Father's pesticide safety training		
No farm work	26	43.3
Farm work and training	11	18.3
Farm work and no training	17	28.3
Anyone in house delays shower after farm work	36	60.0
Anyone in house changes farm clothes inside	50	83.3
Farm work clothes storage		
Everyone stores clothes outside	11	18.3
Anyone stores clothes inside	40	66.7
Anyone stores clothes with other clothes	9	15.0
Farm work clothes laundering		
Everyone launders farm clothes separately	48	80.0
Anyone launders farm clothes with other clothes	12	20.0
Child and mother characteristics		
Child sex		
Female	34	56.7
Male	26	43.3
Child age		
1–2 years	5	8.3
3–4 years	36	60.0
5–6 years	19	31.7
Mother's education		
Primary	34	56.7
Secondary	15	25.0
Greater than secondary	11	18.3
Mother's employment		
None	14	23.3
Part time	16	26.7
Full time	30	50.0

differed in possible sources of para-occupational, residential, and environmental pesticide exposure, as well as safety behaviors and personal characteristics (Table I). The majority of the mothers (68.3%) and fathers (56.7%) of these children were employed as farmworkers. However, almost two in five lived in households with one farmworker, while about one in three lived in households with two farmworkers, and one-quarter lived in households with three or more farmworkers. One-third of the children lived in dwellings that were owned by their parents, while about one-half lived in dwellings which their parents rented and 13.3% lived in dwelling provided to their parents in some other way. About two in five of their mothers described their dwellings as easy to clean. Half of these dwellings had one bathroom. Most (91.7%) lived in dwellings with at least one carpeted room, and almost 70% lived in dwellings with three or more carpeted rooms. The dwellings of 43.3% were adjacent to agricultural fields.

Almost 40% of mothers and 30% of fathers were employed in farmwork, but had not received pesticide safety training. Three in five children lived in households in which individuals employed in farm work did not shower immediately after work, and four in five lived in households in which individuals employed in farm work change out of their work clothes inside the dwelling. However, only 15% of these children lived in households in which farm work clothes were stored with other laundry and 20% lived in households in which farm work clothes were laundered with other work clothes.

More of these children were girls (56.7%) than boys (43.3%). Most were 3 or 4 years of age (60.0%), with one-third 5 or 6 years of age, and 8.3% 1 or 2 years of age. Over half of their mothers had less than a secondary education. About one-quarter of their mothers did not work outside the home, with one-quarter working part-time and one-half working full-time.

OP Pesticide Metabolite Levels

The percent of samples in which the OP pesticide metabolites were less than the limit of detection ranged from a low of 6.7% for DMP to a high of 83.3% for DEDTP (Table II). This percentage was about 20% for the other four metabolites. The levels of the six OP pesticide metabolites detected in the samples varied, with this variability great enough to result in the standard deviation for each metabolite being larger than the mean. For example, the mean level of DETP was 1.41 μg/L with a SD of 2.11, and the mean level of DMDTP was 2.66 μg/L with a SD of 5.31. Some of the children had high levels of OP pesticide metabolites; for example, the maximum value for DEP was 68.69 μg/L, while for DMTP it was 183.27 μg/L.

An examination of the mean level for each OP pesticide metabolite and the summed diethyl and dimethyl metabolites by child sex and by child age indicated that boys had higher levels of metabolites than girls (Table III). Boys had higher mean levels for five of the six individual metabolites, all but DMDTP, and for the summed diethyl and dimethyl metabolites. No discernable pattern of metabolite levels was discernable by child age.

These eastern North Carolina farmworker children had generally higher levels of the six individual metabolites and the summed diethyl and dimethyl levels than those in national reference data (Table IV). Caution needs to be used in comparing these study participants to the national reference data, as the farm worker children were aged 1–6 years and the children in the national reference data were aged 6–11 years. Child age affects how OP pesticides are metabolized, and these differences in metabolism may reduce the comparability of our results with those in the national reference data. The children in this study had higher geometric means for DEP and DETP, and the summed diethyl metabolites than the national reference data, as well as higher levels at each percentile for DEP, DETP, and the summed diethyl metabolites. The geometric means for DEDTP for the children in this study were the same as the national reference data. The levels of DEDTP at each of the percentiles were lower for the children of this study than for the national reference data. The geometric mean and levels at each percentile for DMTP were greater for the children in this study than the national reference data. The levels of DMP through the 90th percentile were higher for children in this study than those in the national reference data. The percentile levels for DMDTP for the children in this study were equivalent or lower than national reference data.

Predictors of OP Pesticide Metabolite Levels

Bivariate and multivariate procedures based on our systematic model of pesticide exposure among children living in farmworker households found no pattern of significant associations between the predictors and levels of OP pesticide metabolites. For example, the bivariate analyses of the associations between the predictors and the summed diethyl and dimethyl OP pesticide metabolite levels found 1 of 36 comparisons had a statistically significant association. With the large number of comparisons, no confidence can be placed in this single significant result.

DISCUSSION

OP pesticide urinary metabolite levels for the children who participated in this analysis are of concern. OP pesticides are known risk factors for delay in neurobehavioral development, cancer, and other health problems [McCauley et al., 2006; Reigart and Roberts, 1999]. We found that farmworker children in eastern North Carolina have relatively high levels of OP pesticide urinary metabolites. The proportion of eastern North Carolina farmworker children in which each of the OP pesticide urinary metabolites was detected is generally equal to or greater

TABLE II. Urinary Levels of Organophosphorus Pesticide Metabolites for 60 Children Aged 1–6 Years Living in Farmworker Families, Eastern North Carolina, 2004

		<LOD		μg/L				
Urinary metabolites	**N**	**N**	**%**	**Mean**	**SD**	**Median**	**Minimum**	**Maximum**
Diethylphosphate (DEP)	59	11	18.6	8.58	10.48	5.97	<LOD	68.69
Diethylthiophosphate (DETP)	60	9	15.0	1.41	2.11	0.79	<LOD	12.40
Diethyldithiophosphate (DEDTP)	60	50	83.3	0.06	0.15	<LOD	<LOD	0.55
Dimethylphosphate (DMP)	60	4	6.7	5.14	5.44	2.75	<LOD	24.88
Dimethylthiophosphate (DMTP)	59	12	20.3	21.23	36.22	6.72	<LOD	183.27
Dimethyldithiophosphate (DMDTP)	60	13	21.7	2.66	5.31	0.67	<LOD	27.06

LOD, limit of detection; SD, standard deviation.

TABLE III. Urinary Levels of Organophosphorus Pesticide Metabolites for 60 Children Aged 1–6 Years Living in Farmworker Families, Total, by Sex, and by Age, Eastern North Carolina, 2004

	N		DEP	DETP	DEDTP	DMP	DMTP	DMDTP	Diethyl sum	Dimethyl sum
Total	60	Mean	8.58[a]	1.41	0.06	5.14	21.23[b]	2.66	64.33	205.58
		(SD)	(10.48)	(2.11)	(0.15)	(5.44)	(36.22)	(5.31)	(72.76)	(303.65)
Sex										
Male	26	Mean	8.75	1.81	.11	5.21	23.05	1.84	68.77	216.26
		(SD)	(6.32)	(2.73)	(.18)	(5.05)	(39.10)	(3.28)	(50.33)	(316.98)
Female	34	Mean	8.44	1.10	.03	5.10	19.81	3.28	60.93	197.41
		(SD)	(12.96)	(1.45)	(.11)	(5.79)	(34.33)	(6.43)	(86.71)	(297.61)
Age										
1–2 years	5	Mean	9.09	1.45	0.08	7.27	27.53	4.40	68.77	280.71
		(SD)	(10.46)	(1.16)	(0.17)	(8.78)	(31.57)	(5.41)	(69.45)	(293.24)
3–4 years	36	Mean	9.45	1.37	0.05	5.07	18.86	1.43	70.64	179.48
		(SD)	(12.12)	(1.78)	(0.14)	(5.65)	(32.99)	(2.29)	(82.30)	(267.62)
5–6 years	19	Mean	6.69	1.47	0.08	4.72	23.94	4.53	51.21	235.25
		(SD)	(6.40)	(2.85)	(0.17)	(4.04)	(43.82)	(8.25)	(53.31)	(374.16)

DEP, Diethylphosphate; DETP, Diethylthiophosphate; DEDTP, Diethyldithiophosphate; DMP, Dimethylphosphate; DMTP, Dimethylthiophosphate; DMDTP, Dimethyldithiophosphate. Units for DMP, DMTP, DMDTP, DEP, DETP, and DEDTP are μg/L. Units for summed concentrations are nmol/L.

[a]N = 17 for DMTP due to insufficient volume of urine available for analysis.

[b]N = 12 for DEP due to insufficient volume of urine available for analysis.

than the proportions from other studies [Mills and Zahm, 2001; Shalat et al., 2003; Thompson et al., 2003; Lambert et al., 2005]. For example, compared to the 211 children aged 2–6 years from Washington State described by Thompson et al. [2003], the percent of the 60 children aged 1–6 years in this study in which OP pesticide urinary metabolites were detected is much greater for DMP (93.3% vs. 19.0% detects), DMDTP (78.3% vs. 45.0%), DEP (81.4% vs. 0.9%), DETP (85.0% vs. 37.0%), and DEDTP (16.7% vs. not reported); for only DMTP (79.7% vs. 88.0%) was there a greater percentage of detectable levels in the Washington State study. Based on means and percentile distributions, the actual levels of OP pesticide urinary metabolites for the farmworker children in this study were generally higher than those reported for national reference data [Barr et al., 2004] and for other samples of children residing in other agricultural communities [Fenske et al., 2005]. Therefore, efforts to reduce the exposure of these children, as well as all farmworker children, to OP pesticides are needed.

The efficiency of efforts to reduce OP pesticide exposure among farmworker family members would benefit from delineating modifiable risk factors that account for elevated levels of exposure. Our study participants had considerable variability in their levels of OP pesticide urinary metabolites. They also had considerable variability in exposure characteristics, as well as household pesticide safety behaviors, and personal and parent characteristics. Our analysis of OP pesticide metabolite predictors, based on a literature based, systematic exposure model [Quandt et al., 2006], could not determine significant associations between potential risk factors and metabolite levels (even though we tried different measures of outcomes and predictors, and several analytic techniques). Our results, while unfortunate, are not unexpected. While most analyses of pesticide exposure among farmworkers and their family members have documented high levels of exposure, few have been able to delineate statistically significant predictors. For example, Coronado et al. [2004] found only one significant association in 33 comparisons (11 predictors each for the levels of DMP, DMTP, and DMDTP) in their sample of 211 farmworker children aged 2–6 years. Fenske et al. [2005] review their substantial body of research on child exposure to pesticides and do not differentiate predictors of exposure among farmworker children. Rather, their most striking finding is that the children of applicators have higher metabolite levels than other children in agricultural communities, including farmworker children. Finally, Lambert et al. [2005] found that DAP levels among farmworker children did vary across the season, and that the children of pear pickers had higher levels of DMTP than did the children of berry and cherry pickers. Therefore, existing analyses do not provide direction in selecting modifiable risk factors that will reduce farmworker child OP pesticide exposure.

Several factors may account for the lack of association between predictors and OP pesticide metabolite levels among farmworker children. Pesticide exposure in farmworker populations may be so intense and widespread, spatially and temporally, that delineating specific risk factors is extremely difficult, if not impossible. This is what Arcury et al. [2005] argue in their analysis of nine farmworker

TABLE IV. Geometric Means and Percentiles for Urinary Levels of Organophosphorus Pesticide Metabolites for 60 Children Aged 1–6 Years Living in Farmworker Families, Casa y Campo Study, Eastern North Carolina, 2004, and for Children Aged 6–11 Years From the NHANES 1999–2000 Study*

		Percentile of distribution				
Urinary metabolite	**Geometric mean**	**25th**	**50th**	**75th**	**90th**	**95th**
Diethylphosphate (DEP)						
Casa y Campo	3.38	1.28	5.97	13.10	18.32	22.48
NHANES	1.32	<LOD	1.20	3.10	7.50	13.00
Diethylthiophosphate (DETP)						
Casa y Campo	0.76	0.35	0.79	1.46	3.79	6.70
NHANES	NC	<LOD	0.59	0.90	1.70	3.13
Diethyldithiophosphate (DEDTP)						
Casa y Campo	NC	<LOD	<LOD	<LOD	0.35	0.43
NHANES	NC	<LOD	0.08	0.19	0.43	0.85
Dimethylphosphate (DMP)						
Casa y Campo	2.93	1.14	2.75	8.36	12.70	18.8
NHANES	NC	<LOD	1.00	4.40	10.00	21.0
Dimethylthiophosphate (DMTP)						
Casa y Campo	6.20	2.35	6.72	25.1	58.8	79.4
NHANES	2.72	<LOD	4.10	20.00	40.0	62.0
Dimethyldithiophosphate (DMDTP)						
Casa y Campo	0.80	0.22	0.67	2.12	8.05	15.4
NHANES	NC	<LOD	<LOD	4.30	26.0	32.0
Diethyl Sum						
Casa y Campo	32.6	7.94	45.6	92.5	146	181
NHANES	13.2	4.70	15.6	35.9	87.5	136
Dimethyl Sum						
Casa y Campo	87.6	33.0	78.6	261	597	753
NHANES	49.4	23.4	90.6	270	460	679

LOD, limit of detection; NC, not calculated because proportion of results below the LOD was too high to provide a reliable result.
Units for DEP, DETP, DEDTP, DMP, DMTP, and DMDTP are μg/L. Units for summed concentrations are nmol/L.
*Barr et al. [2004].

families from western North Carolina and Virginia. If this is the case, immediate and rigorous occupational and residential interventions are required to reduce the pesticide exposure of all farmworker families. Existing regulations for pesticide application and the use of personal protection equipment would also need to be greatly strengthened. However, several studies [e.g., Koch et al., 2002; Kissel et al., 2005; Lambert et al., 2005] have reported temporal variability in the OP pesticide metabolite levels of children in agricultural communities, including farmworker children. Therefore, the inability to identify specific risk factors for levels of OP pesticide urinary metabolites can only be partially attributed to endemic pesticide exposure in farmworker populations.

Methodologically, the lack of associations could result from insufficient power due to small samples. Most studies that have examined predictors of pesticide exposure among children in farmworker families have had relatively small samples. For example, analyses by Fenske and colleagues [Lu et al., 2000; Fenske et al., 2000a] have included 13 farmworker children, 49 applicator children, and 14 reference children, while the analysis by Lambert et al. [2005] included 114 children in farmworker families and 61 reference children. Analyses by Coronado et al. [2004], Curl et al. [2002], and Strong et al. [2004] use data from a common sample of 211 children in farmworker families, but the one analysis of these three that examined predictors of children's exposure [Coronado et al., 2004] used dichotomous measures of OP urinary metabolites (detection/non-detection of DMP, DMPT, DMDTP) and still found only one significant association in 33 comparisons. Arcury et al. [2005] use a sample of 16 children from 9 farmworker households, and report that OP pesticide urinary metabolite levels are associated with number of household residents with agricultural employment, dwelling adjacency to agricultural fields, and residing in a dwelling judged difficult to clean; however, these results are based on a case-based qualitative analysis rather than statistical associations. Other analyses of children's agricultural pesticide exposure have also relied on relatively small samples; for example, Fenske and colleagues [2002] include 109 children living agricultural communities, Koch et al. [2002] include 44 children from an agricultural region, and Shalat et al. [2003] collected data from 52 children living in a Rio Grande Valley colonia.

Other likely factors related to the dearth of associations between suspected risk factors and pesticide metabolite levels result from limitations in measurement. The collection of outcome and predictor measures needs to be refined so that the association between predictors and outcomes makes more temporal sense. Most research has been based on a single exposure measure (one urine sample) in an agricultural season. OP pesticide metabolites should be eliminated within 48–72 hr. A single urine sample that is not attached to proximal measures of actual exposure behaviors cannot tell us very much about the causes of exposure. Fenske et al. [2005:1656] suggest the same need to account for temporal variation in exposure when they conclude that, "future studies should be designed as longitudinal investigations with frequent repeated measurements to capture peak exposures and characterize intrapersonal and interpersonal variability," and that "studies that seek to categorize children's exposure in these [agricultural] communities will need to sample both peak and non-peak exposure periods, and will need to evaluate multiple exposure pathways."

Young et al. [2005] collected two prenatal and one postnatal urine sample from mothers; however, OP metabolite levels were the predictors in this analysis. Koch et al. [2002] collected biweekly samples over a 21-month period from 44 children 2–5 years old living in an agricultural community; each child gave 16–26 urine samples. While finding temporal variation in OP pesticide urinary metabolite levels, they found no association with child age, parental occupation, or residential proximity to fields. However, while parental occupation and residential propinquity to fields are risk factors for pesticide exposure, they are not proximate predictors of exposure. Proximate measures would include whether a parent actually worked in agriculture during the 3 days before the collection of a urine sample, as well as whether the parent had helped apply pesticides on any of these days, had changed out of work clothes before coming home, had stored these work clothes outside the home, and had showered immediately after work and before coming into physical contact with the child. Similar proximate measures describing agricultural fields near the dwelling would also be needed. More precise and proximate measures of pesticide exposure are needed. Most research asks about characteristics or behaviors for the previous year or current agricultural season. Measures of exposure risk factors that are contemporaneous with measures of exposure are needed.

Future research should use a cohort of children with repeated measures of exposure (urine samples) across an agricultural season. Data on proximal predictors of exposure need to be collected for the time when urine samples are collected (e.g., detailed information on parents' work and tasks, parents' pesticide safety behaviors, and on child activities for the 3 days prior; detailed information on pesticides used in the places where parents work, as well as current residential pesticide application, and on current pesticide application in neighboring fields). With such detail, it will be possible to determine (a) temporal variability in exposure and (b) the proximate determinants of exposure.

In summary, this analysis found that the 1–6-year-old children residing in farmworker households in eastern North Carolina had generally high levels of OP pesticide metabolites in their urine. Modifiable predictors of urinary metabolite levels, such as indicators of para-occupational and residential pesticide exposure, and parental safety behaviors, did not have a statistically significant association with the levels of OP pesticide urinary metabolites among these children. The inability of this analysis to differentiate predictors of OP pesticide metabolite levels is common among investigations of farmworker child pesticide exposure. Greater precision in sampling and measurement is required if research is to determine the causes of pesticide exposure among farmworker children. Efforts to reduce the exposure of these children to pesticides must be redoubled.

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