Exposure to Indoor Pesticides during Pregnancy in a Multiethnic, Urban Cohort

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Evidence is growing that indoor pesticide exposure is of considerable magnitude in the United States and that pesticide concentrations may be especially high in urban areas. Of particular concern is exposure of pregnant women because animal data suggest that exposure to pesticides during pregnancy and early life may impair neurodevelopment in the offspring. To investigate the relationship between prenatal exposure to indoor pesticides and infant growth and development, we are conducting a prospective, multiethnic cohort study of mothers and infants delivered at Mount Sinai Hospital in New York City. This article provides data on pesticide exposure based on questionnaire items and analysis of maternal urinary metabolite levels among 386 women. Both the questionnaire and laboratory data revealed that exposure to indoor pesticides was considerable. The proportion of women estimated from questionnaire data as having been exposed during pregnancy to indoor pesticides (approximately 70%) was somewhat lower than the 80–90% of American households who reportedly used pesticides in previous surveys, but some of the latter surveys included both indoor and outdoor pesticide use. Urinary metabolite levels of 3,5,6-trichloro-2-pyridinol (TCPy; median = 11.3 µg/g creatinine), phenoxybenzoic acid (PBA; median =19.3 µg/g creatinine), and pentachlorophenol (PCP; median =7.3 µg/g creatinine) were higher than those reported in other studies of adults in the United States. Furthermore, no associations were evident between the pesticide questionnaire data and the urinary metabolites. Assessments of sociodemographic and building characteristics with questionnaire data and the metabolite levels revealed no consistent trends. Significant temporal variations were observed for urinary PBA but not TCPy or PCP. The temporal variations for PBA were consistent with seasonal spraying of pyrethroid pesticides. These data underscore the need to assess the potentially adverse effects of pesticide exposure on fetuses and infants and the importance of finding alternative methods for pest management to reduce pesticide exposures. *Key words:* **chlorpyrifos, exposure assessment, pesticides, urinary biomarkers.** *Environ Health Perspect* **111:79–84 (2003). [Online 3 December 2002] doi:10.1289/ehp.5619 available via** *http://dx.doi.org/*

Traditionally, pesticide exposure has been assessed in relation to its use in agriculture or other occupations. However, there is growing evidence that residential pesticide exposure is of considerable magnitude (*1–3*) and that pesticide concentrations may be higher in urban than in rural areas (*4*). Of particular concern is exposure of pregnant women and their fetuses because little is known about the potential developmental hazards of such exposure.

A study of Minnesota households with children found that pesticide products were stored in 97% of the households investigated, and as many as 88% of the households reportedly had used pesticides within the past year (*5*). Similarly, 85% of minority women in a New York City study reported that pest control measures had been used in their home during pregnancy (*6*). In the state of New York, including rural areas upstate, the largest quantity of pesticides used by commercial applicators was in the urban boroughs of Manhattan and Brooklyn, and the most frequently used pesticide was chlorpyrifos (CP) (*7*). It has been shown that considerable quantities of pesticide residues persist in indoor air and on indoor surfaces after pesticide application. Studies of CP have shown that residues persist for up to 2 weeks after a single broadcast application, with potential exposure to young infants reaching levels 60–120 times greater than the U.S. Environmental Protection Agency (EPA) recommended reference levels (*8,9*).

Pesticide metabolites have been assessed both in adults and children, but no published data are available on metabolites in pregnant women. To establish reference range concentrations for pesticide residues, urine was collected from 1,000 adults between 1988 and 1994 in a subset of participants in the National Health and Nutrition Examination Survey III (NHANES III) (*10*). In this population, the CP metabolite 3,5,6-trichloro-2-pyridinol (TCPy) and napthalene and carbaryl metabolites (1-NAP) were detected in more than 80% of the samples. The National Human Exposure Assessment Survey (NHEXAS-MD) (*11*), which serially sampled 80 adults from Maryland, reported detectable metabolites in 96% of the samples for TCPy and 85% for 1-NAP. In the Minnesota Children's Pesticide Exposure Study (MNCPES) (*4*), TCPy was detected in 97% of the children's urine samples, and 1-NAP was detected in 52% of the samples. However, in a recent study in an agricultural community in Wisconsin, only 24% of children's urine samples had measurable TCPy concentrations (*12*). Because the half-lives of these compounds are short (*13–15*), these data suggest that a large proportion of Americans are continuously exposed to low doses of these pesticides.

The present study was conducted to examine the effects of exposure to indoor pesticides on fetal growth and neurodevelopment in a cohort of infants delivered at Mount Sinai Hospital in New York City. In this article we present exposure data on indoor pesticides as measured by questionnaire and maternal urinary pesticide metabolites among 386 mothers.

Materials and Methods

The Children's Environmental Health Study is a prospective study, which is following an ethnically diverse cohort of mother–infant pairs at Mount Sinai Hospital in New York City. The study has currently enrolled 479 pregnant women. The results presented in this article are based on 386 mothers who gave birth between May 1998 and July 2001.

The mothers were recruited consecutively during early pregnancy from the prenatal clinic and two private practices at Mount Sinai Hospital during March 1998 to May 2001. The study is limited to primiparas with singleton births. Additional exclusion criteria were women who had their first prenatal visit after 26 weeks of gestation; those who had serious chronic diseases such as diabetes, hypertension, or thyroid disease or who developed a serious pregnancy complication that could affect fetal growth and development; and women who consumed > 2 alcoholic beverages (wine, beer, hard liquor) per day or who abused illegal

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drugs. Further, mothers and infants were excluded if the child was born with congenital malformations or severe prematurity (< 1,500 g or < 32 weeks of gestation). Mothers who agreed to participate signed a written consent form according to the guidelines of the Institutional Review Board of the Mount Sinai School of Medicine.

A questionnaire was administered to the mothers during their third trimester to obtain information on characteristics such as environmental exposures, sociodemographic characteristics, maternal health, maternal smoking, alcohol consumption, and caffeine intake. Maternal pesticide exposure was assessed according to such characteristics as the presence of insect or rodent problems in the home, use of pesticides by a household member or exterminator, fumigation of apartment, and application of pesticides in common areas of the apartment building. Pesticide use encompassed any type of pest control including sticky traps, bait traps, gels, can sprays, boric acid, pest bombs, and sprays by exterminators. The questionnaire was administered in either English or Spanish by bilingual interviewers. Spot maternal urine samples were obtained during the third trimester at the time of routine blood sampling.

We determined three phenolic metabolites of pesticides in urine: TCPy, 3-phenoxybenzoic acid (PBA), and pentachlorophenol (PCP). TCPy is one of the most commonly detected pesticide metabolites. PBA is a possible metabolite of several pyrethroid insecticides, including sumithrin, permethrin, and cypermethrin. Sumithrin was used to spray against the West Nile virus in New York City during the summer of 2000. PCP was widely used as a wood preservative until the 1970s and is also a metabolite of hexachlorobenzene (HCB).

We adapted the analytical method from reported methods (*13,16,17*). Samples were treated with acid hydrolysis, followed by solid-phase extraction with a C18 column. HPLC with ultraviolet detection was used for quantitation (290 nm) and diode array detection for confirmation at two additional wavelengths (i.e., 273 and 302 nm for TCPy), based on scans of external standards. For peaks with a concentration more than four times the limit of detection (LD), we considered values missing if the confirmation spectra were not acceptable. For values in the range of 100 µg/L, we used half the value if the HPLC peak appeared to be a shoulder or coeluted peak with a spectrum that was equivocal (i.e., one of two confirmation wavelengths was acceptable). We defined the LD as three times the standard deviation of water blanks run with each batch over the course of the analysis (n = 44). This definition is commonly used because it provides data with a known reliability (*18*). The LDs were 12.0 µg/L for TCPy, 16.0 µg/L for PBA, and 23.0 µg/L for PCP. The proportions of our values below LD were 58% for TCPy, 45% for PBA, and 82% for PCP. Using another algorithm, when the blank urine pool [used for quality control (QC)] and blanks were considered together (*19*), the LD was 2.0 µg/L for TCPy, comparable to the instrumental limit of detection and similar to the median levels in the blanks (3.0 µg/L). For QC pools fortified with analytes and run with each batch, the recoveries were 80% [standard deviation (SD) 27%, n = 75], and the internal standard recoveries were similar for samples and standards (65%, SD 10%, n = 623).

To adjust for intrapersonal variability in urine dilution, analyte concentrations were normalized to creatinine. Creatinine was assayed using a kit from Sigma Chemical Company (St. Louis, MO). We excluded samples for which creatinine was < 10 mg/dL from the data set (n = 5). Although there is no consensus on the best method of normalizing untimed spot urine samples to account for diurnal variation in dilution, it is widely accepted that some correction is necessary, at least for adults. Creatinine and specific gravity are commonly used for such correction (*20*). Heterogeneity in factors that can affect creatinine elimination (*21*), such as age and body size, are likely to be minimal in our study group. Further, we wanted to avoid misclassification of exposure due to urine dilution. For example, when we corrected TCPy for creatinine, 52/370 values were discordant for corrected versus uncorrected values (i.e., they switched from above to below the LD or the reverse). The Spearman correlation for all 370 values was 0.8855 (creatinine corrected vs. uncorrected); for 365 values, excluding those with creatinine < 10 mg/dL, the correlation was 0.8970. Both uncorrected and creatinine corrected values are, however, presented for comparison purposes.

We used all observed positive values rather than setting values lower than the LD to zero or assigning a single imputed value (*22*). In statistical analyses, negative and zero values of metabolites (n = 8 for TCPy, n = 10 for PBA, and n = 35 for PCP) were set to the lowest positive value for that compound as observed in these samples. This procedure is consistent with the recommendation to use values from a simulated normal distribution below the LD rather than an imputed value, such as one-half the LD. Values below the LD were largely positive and resembled a log normal distribution. The lowest positive values were 0.072 µg/L for TCPy, 0.028 µg/L for PBA, and 1.0 µg/L for PCP. Using this approach, we obtained generally lower estimates for the lower quantiles than the imputed approach. For TCPy, for example, we obtained 0.3 µg/L for the 10th percentile, 1.8 µg/L for the 25th percentile, and 7.5 µg/L for the 50th percentile using the observed value or the lowest positive values. We obtained 6.0 µg/L for the 10th percentile, 6.0 µg/L for the 25th percentile, and 6 µg/L for the 50th percentile using one-half the LD for all nondetectable values (*22*). The values

Table 1. Indoor pesticide exposure during pregnancy reported by questionnaire, Children's Environmental Health Study, Mount Sinai Hospital, 1998–2001.

Questionnaire items	Percent (n = 386)
Insect problem in home[a]	47.9
Rodent problem in home[a]	27.5
Pesticide use by household member[b]	46.4
Pesticide use by exterminator[b]	25.9
Pesticide use by building staff in hallways/common areas[a]	31.6
Fumigation of apartment[a]	6.7
Any reported indoor pesticide use[c]	72.3
Flea or tick control of pets[b,d]	37.4
Use of lice control on self[b]	0.8
Use of mothballs[b]	9.6

[a]During past year. [b]During pregnancy. [c]Combination of pesticides used by household member, exterminator, and building staff in hallways/common areas, and fumigation of apartment. [d]Among those with pets (n = 166).

Table 2. Percentiles of pesticides metabolites (µg/L) and creatinine (mg/dL) for maternal urine samples, Children's Environmental Health Study, Mount Sinai Hospital, 1998–2001.

		Percentile				
Analyte	n	10th	25th	50th	75th	90th
TCPy	365	0.3	1.8	7.5	25.7	61.2
PBA	307	0.4	2.4	18.3	40.6	126.9
PCP	361	1.0	2.0	7.0	18.0	52.0
Creatinine	373	24.7	46.9	86.5	137.4	202.9

TCP values include 58% < 12 µg/L, the LOD; PBA values include 45% < 16 µg/L, the LOD; PCP values include 82% < 23 µg/L, the LOD. Five urine samples with creatinine < 10 mg/dL were excluded.

Table 3. Percentiles of pesticide metabolite concentration (µg/g creatinine) for maternal urine samples, Children's Environmental Health Study, Mount Sinai Hospital, 1998–2001.

		Percentile				
Analyte	n	10th	25th	50th	75th	90th
TCPy	365	0.4	1.8	11.3	31.7	70.2
PBA	307	0.4	4.8	19.3	57.2	184.1
PCP	361	1.1	2.4	7.3	28.4	67.0

Five urine samples with creatinine < 10 mg/dL were excluded.

for the 75th and 90th percentiles remained the same according to both methods. The medians for PBA were identical (18.3 μg/L) for both methods, while the median for PCP was higher for the one-half LD method (11.5 μg/L) than for the method we used (7.0 μg/L). We also analyzed the metabolites by deleting nonpositive values and obtained similar results.

Statistical methods. We assessed the significance of associations between categorical variables of pesticide exposure from the questionnaire and categorical sociodemographic variables and dwelling characteristics using chi-square analysis. Because the urinary metabolites were not normally distributed, we used nonparametric methods (Wilcoxon rank-sum test and Kruskal-Wallis test) (*23*) to test for differences in the median metabolite level between groups defined by various sociodemographic variables and dwelling characteristics. In addition, the various factors affecting urinary metabolite levels were examined in multiple regression analyses. For these analyses, the metabolite data were log-transformed to make the data more nearly normal, and PROC GLM of SAS software (SAS Institute, Cary, NC) was used to fit the models. In these models, the metabolite levels were the dependent variable and the various sociodemographic and other variables were the independent variables. The multiple linear regression results, however, did not improve the results generated in the nonparametric analyses, and therefore those results are not presented.

We assessed seasonality by examining the month and year of the time of maternal urine collection. Because of small numbers, the data were categorized by quarter: January, February, March; April, May, June; July, August, September; and October, November, December.

Results

The study population comprised 386 pregnant women, including 78 Caucasians, 104 African Americans, 198 Hispanics, and 6 who were categorized as "other" (mixed racial/ethnic group). The patients were drawn predominantly from East Harlem but also from other parts of New York City. The women were relatively young with 35.5% under the age of 20, 44.0% between the ages of 20 and 30, and 20.5% 30 years of age or older. Of the 386 women, 28.2% were married, 24.6% were cohabiting with the baby's father, and 47.2% were single. Consistent with the young age distribution, 29.5% had not completed high school, 20.5% were high school graduates, 26.2% had received some college education, and 23.8% were college graduates.

Table 1 provides the frequency of various questionnaire items related to pesticide exposure. Almost half (47.9%) of the respondents reported having had an insect problem in the home, and more than a quarter (27.5%) reported having had a rodent problem. During the pregnancy, close to half (46.4%) stated that they or another household member had applied pesticides inside the home. Among those who reported pesticide use, 34.3% reported use of bait traps, 28.7% can sprays, 12.2% gels, 6.1% boric acid, 4.4% sticky traps, 2.2% pest bombs, and 12.1% miscellaneous pest control products. When a composite index of indoor pesticide exposure was calculated on the basis of a positive response to either household or exterminator application, fumigation, or pesticide use in common areas, a total of 72.3% were classified as having been exposed (Table 1). Use of flea or tick control, lice control, or use of mothballs was not included in the latter estimate because the major focus of this study was on the use of chlorpyrifos.

Table 2 presents the 10th, 25th, 50th, 75th, and 90th percentiles for the urinary pesticide metabolites as well as for creatinine. Table 3 gives the corresponding percentiles for the metabolites corrected for creatinine. The respective medians were 11.3 μg/g creatinine for TCPy, 19.3 μg/g creatinine for PBA, and 7.3 μg/g creatinine for PCP. As is evident from the percentiles, there was considerable variation in the values of all three metabolites.

The pesticide questionnaire responses were also compared to tertile distributions of the three pesticide metabolites. There were no associations between the tertile distributions and the responses to any of the questionnaire items, including exterminator application or fumigation, which would include the higher toxicity methods.

The distributions of questionnaire pesticide exposure and the median urinary metabolites according to selected sociodemographic characteristics are shown in Table 4. When only pesticide use by a household member was considered, significantly higher proportions were seen for younger women, African Americans, or Hispanics compared to Caucasians, single or cohabiting women, and those in the lowest educational level. It should be noted that these characteristics were highly correlated. However, when any reported pesticide use was evaluated, no significant sociodemographic differences were seen, although the percentages tended to be higher among younger women (p = 0.09, Mantel-Haenszel test for trend).

The TCPy levels were significantly higher for those who had completed at least a high school education, but levels did not differ for the other sociodemographic characteristics. PBA levels were higher among those who were married or cohabiting and among those who had completed high school or higher educational level. Caucasian women also tended to have higher PBA levels, but the racial/ethnic differences (excluding the "other" category) were not statistically significant (p = 0.08). For PCP, there was some suggestion that women who were living with the baby's father had an elevated level (p = 0.07), but there were no differences by age, race/ethnicity, or maternal education. When the above analysis was repeated for the log of the metabolites using a generalized linear model (GLM), the findings remained the same, with the exception that married or cohabiting women had significantly higher PCP levels than single women (p = 0.02).

Table 4. Distribution of pesticide exposure by questionnaire item and maternal metabolite levels by sociodemographic characteristics, Children's Environmental Health Study, Mount Sinai Hospital, 1998–2001.

Sociodemographic characteristics	Pesticide use by household member (%)	Any reported pesticide use (%)	Median maternal urinary metabolite levels (μg/g creatinine)		
			TCPy	PBA	PCP
Maternal age					
< 20 (n = 137)	54.7*	75.9	10.5	13.3	5.7
20–24 (n = 127)	45.7	73.2	13.7	19.3	9.6
25–29 (n = 43)	51.2	69.8	7.8	16.8	7.3
30–34 (n = 57)	33.3	66.7	10.4	22.7	7.0
≥ 35 (n = 22)	22.7	63.6	7.5	80.1	10.3
Race/ethnicity					
White (n = 78)	30.8*	68.0	11.4	25.3	12.6
African American (n = 104)	50.0	76.0	9.1	13.4	6.5
Hispanic (n = 198)	50.5	72.0	12.9	16.8	7.3
Other (n = 6)[a]	50.0	66.7	4.3	235.5	4.7
Marital status					
Married (n = 109)	33.0**	68.8	10.6	26.0*	7.5
Living with baby's father (n = 95)	52.6	73.7	12.9	23.3	10.7
Single/divorced/widowed/separated (n = 182)	51.1	73.6	9.5	12.6	6.7
Maternal education					
Lower/middle school (n = 113)	57.5**	78.1	7.8*	9.0**	7.1
High school graduate (n = 79)	45.6	70.9	15.9	37.4	7.1
Some college (n = 101)	47.5	73.3	14.5	21.3	7.5
College graduate (n = 93)	32.3	65.2	10.6	25.3	7.5

[a]The "other" category was excluded in the analysis because of small numbers. *p < 0.05. **p < 0.01.

Selected building characteristics were also considered with respect to pesticide questionnaire items and the pesticide metabolites (Table 5). Pesticide use by a household member as well as any reported pesticide application were significantly higher for those in public or private rental housing than in those who owned their apartment/house. Any reported pesticide use was also significantly higher for those living in apartments as compared to separate dwellings ($p = 0.01$). No differences were evident with respect to the age of the building, although a substantial number stated that they did not know whether the building was constructed before 1960 or after 1960 ($n = 51$). The presence of an insect or rodent problem was also assessed in relation to the building characteristics (data not shown). With respect to insect problems, there were no significant associations, although those who owned their apartment or house tended to report a lower proportion of insect problems ($p = 0.10$). In regard to the reporting of rodent problems, the proportion was highest for those in low-rise apartment buildings and lowest for those in public housing. No associations were seen between the building characteristics and the TCPy levels. The median PBA level was significantly lower for those in public housing as compared to those who lived in private rental apartments or owned their apartment/house. Those who lived in a separate dwelling (house) tended to have higher PCP levels as compared to those in apartment buildings ($p = 0.06$).

The metabolite levels were also assessed according to the season and the year of the urine collection. No seasonal variations were evident for TCPy and PCP, nor was there any evidence that the levels of these metabolites changed during the time period 1998–2001 (Figures 1 and 2). However, a significant increase in PBA levels was seen between 1998–1999 and 2000 ($p < 0.001$; Figure 3), but it should be noted that urinary collections were not obtained before the spring of 1998 or after the winter of 2000–2001. The highest levels were evident during the months of July, August, and September of the year 2000. The log-transformed values of PBA were assessed in a GLM model that tested for such potential confounders as maternal age, race, and body mass index. Adjustment for these variables did not affect the seasonal or yearly variations.

Discussion

In this study, indoor pesticide exposure was assessed by both questionnaire data and laboratory detection of pesticide residues in maternal urine. Both data sources revealed that exposure to indoor pesticides was considerable in this multiethnic urban cohort, but no associations were evident between the questionnaire and pesticide metabolite data. Similarly, sociodemographic and such other potential risk factors for pesticide exposure as dwelling characteristics were not consistently related to the questionnaire data and the specimen levels.

Previous surveys have reported that 80–90% of American households use pesticides and that 80% or more of personal exposures come from indoor sources (*5,24*). The proportion of women who reported that they or a household member had applied pesticides during pregnancy in this study is considerably lower (46.4%), but when pesticide exposure by exterminators or building employees was considered, the estimate of indoor pesticide exposure increased to 72.3%. The latter figure is still somewhat lower than the 85% who reported use of pesticides in their homes in a cohort of African-American and Dominican women in New York City (*6*). Our population is composed of Caucasian, African-American, and Hispanic (mainly Puerto Rican) women. Although we observed no significant socioeconomic differences in any reported pesticide use, the proportions tended to be higher for younger women, African Americans, and less well educated women.

Table 5. Distribution of pesticide exposure by questionnaire item and maternal metabolite levels by dwelling characteristics, Children's Environmental Health Study, Mount Sinai Hospital, 1998–2001.

Dwelling characteristics	Pesticide use by household member (%)	Any reported pesticide use (%)	Median maternal urinary metabolite levels (µg/g creatinine)		
			TCPy	PBA	PCP
Type of dwelling					
High-rise building (> 7 stories) ($n = 154$)	44.7	70.1**	8.6	17.9	7.0
Low-rise building (≤ 7 stories) ($n = 43$)	51.7	78.2	13.1	19.8	7.1
House ($n = 43$)	35.2	57.4	12.8	29.5	12.1
Residential ownership					
Public housing ($n = 124$)	48.4**	76.6**	8.6	13.9*	6.4
Private rental ($n = 218$)	50.5	73.9	12.9	20.2	8.2
Owner occupied ($n = 43$)	19.5	51.2	14.0	27.7	6.7
Age of building (year built)					
≤ 1960 ($n = 193$)	43.0	72.0	11.5	19.5	7.3
> 1960 ($n = 142$)	48.6	72.5	9.6	19.5	6.9

*$p < 0.05$. **$p < 0.01$.

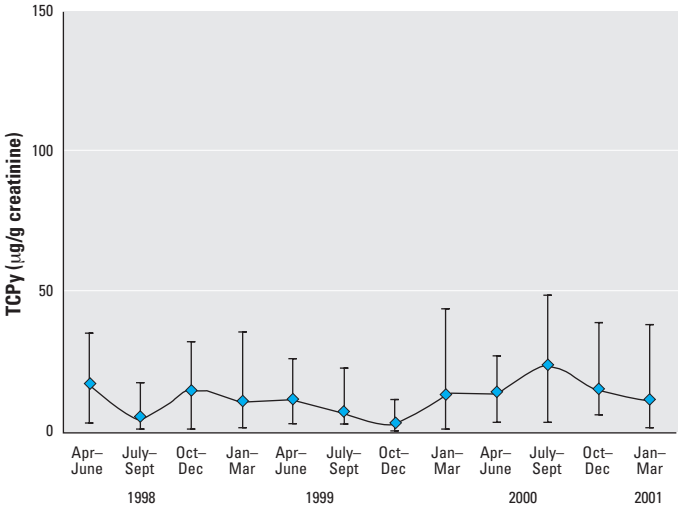

Figure 1. Median and interquartile values of TCPy by quarter between April 1998 and April 2001.

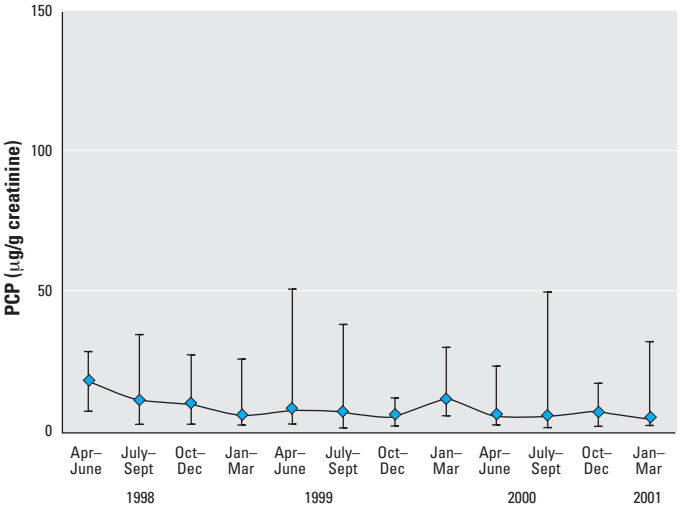

Figure 2. Median and interquartile values of PCP by quarter between April 1998 and April 2001.

In contrast, the pesticide metabolite levels in our population tended to be higher than those reported in previous studies. In our study, the median TCPy concentration was 11.3 μg/g creatinine, as compared to 2.2 μg/g creatinine in the NHANES III survey (*10*) and 4.6 μg/g creatinine in the NHEXAS-MD study (*11*). The median concentration for TCPy (8.2 μg/L) in the MNCPES study (*4*), which was not corrected for creatinine, was comparable to our uncorrected value (7.5 μg/L). A recent study of children in an agricultural community in Washington State found a median of 0 and means ranging from 1.3 to 6.0 μg/L depending on the proximity to pesticide-treated farmland (*8*). It should be noted that the LDs in these studies ranged from 1 μg/L in the NHANES (*10*) and NHEXAS (*11*) studies to 8 μg/L in the Washington study (*8*) and 12 μg/L in our study. Although the LD cut-offs could affect the study results, our detectable proportion (42%) was considerably higher than the 24% in the Washington study, despite our higher cut-off.

Our median PCP level (7.3 μg/g creatinine) is also higher than that reported for NHANES III (1.2 μg/g creatinine) (*10*). Because PCP concentrations were greater in the NHANES II survey (*25*), Hill et al. (*10*) suggested that this reflects the decreased use of PCP as a wood preservative as result of the U.S. EPA's decision to designate PCP as a restricted-use pesticide. Our values are more comparable to a recent German study that reported PCP levels both in adults [geometric mean (GM), 2.7 μg/L] and in children (GM, 4.2 μg/L) (*26*).

As noted previously, PBA is a possible metabolite of several pyrethroid insecticides, including sumithrin, permethrin, and cypermethrin. The median value in our sample (18.3 μg/L or 19.3 μg/g creatinine) is higher than levels in previous reports (*27,28*). For example, we found 55% of our PBA samples above the LD, whereas a recent study only found 12% of samples detectable (*28*). The higher levels in our study may reflect the increasing use of pyrethroids for residential pesticides and/or the spraying against the West Nile virus in New York City during the summer and fall of 2000 (*29*). The variant results may also reflect differences in assay techniques.

Only limited information is available on sociodemographic or dwelling correlates of pesticide metabolite levels. In the NHEXAS study of serial samples from 80 individuals in Maryland during 1995–1996 (*11*), the GM TCPy concentrations were significantly higher for Caucasians as compared to African Americans and for those with higher educational levels but no differences were reported by age, gender, or household income. The study of children in Seattle observed no differences in dialkylphosphate concentrations by age, sex, family income, community or housing type (*30*). Similarly, the MNCPES study (*4*) found no consistent racial or income-related trends in chlorpyrifos or malathion metabolites. Furthermore, outdoor pesticide use was a significant predictor of metabolite levels in the Seattle study (*30*), and the MNCPES study (*4*) oversampled households with frequent pesticide use. Thus, there are few comparable data for exposure primarily limited to indoor pesticide use among racially/ethnically heterogeneous urban residents or for pregnant women. Nevertheless, the weak socioeconomic differentials for TCPy and PCP in our sample are consistent with the available data. Although maternal education emerged as a significant factor for PBA levels in our study, no consistent trend was evident.

Seasonal variation in pesticide levels has been observed both in air and urine samples, with higher concentrations during summer (*2,4*) or spring and summer (*11*). We detected no seasonal variations for TCPy or PCP. However, significant temporal variations were observed for PBA where the levels were highest during summer and fall for the year 2000. It might be speculated that the spraying of the pyrethroid sumithrin against West Nile virus, which occurred between 19 July and 25 September 2000 (*29*), may have contributed to the increased levels.

The lack of associations between the questionnaire and metabolite data is understandable. Urinary metabolites have the advantage that they reflect not only intake but also uptake and clearance of pesticide. Furthermore, metabolites reflect exposures from various sources, including the workplace and, more importantly, the diet. However, because all three of the pesticides assessed have short half-lives, the metabolites generally reflect only recent exposure. Reports that pesticides such as CP can persist on indoor surfaces for several weeks after the use of broadcast spray suggest that the urinary metabolites can reflect somewhat longer exposures than their half-lives indicate. Nevertheless, the rapid excretion from the body makes metabolite results susceptible to underestimation of chronic or intermittent exposure. Questionnaire information, on the one hand, may give better information on the history of exposure but, on the other hand, tends to give limited information on the specific type and amount of pesticide exposure as well as exposures through other sources such as the diet. Such information is also subject to over- and underreporting, particularly as the participant may not remember use or not be aware of spraying in multiunit dwellings. Limitations and strengths of either approach must be kept in mind when interpreting the results of this and similar studies. These considerations also underscore the difficulty of accurately estimating pesticide exposure.

There is a clear need for more data on pesticide exposure among pregnant women because fetuses are known to be particularly vulnerable to environmental toxicants. Use of alternative methods, such as Integrated Pest Management, which uses less toxic substances, should also be encouraged to reduce pesticide exposure.

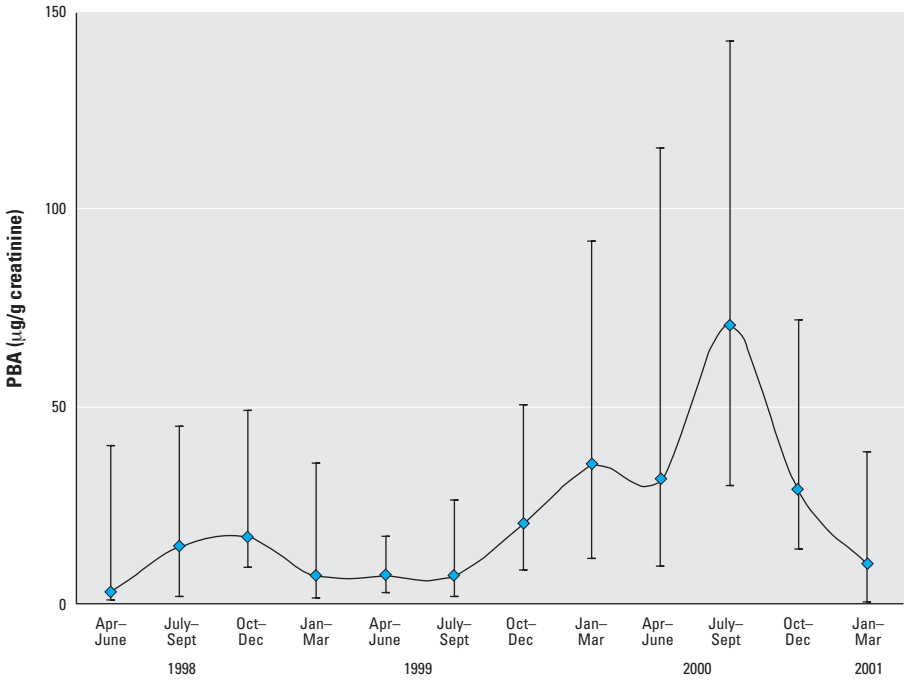

Figure 3. Median and interquartile values of PBA by quarter between April 1998 and April 2001.

References and Notes

1. Lewis RG, Fortmann RC, Camann DE. Evaluation of methods for monitoring the potential exposure of small children to pesticides in the residential environment. Arch Environ Contam Toxicol 26:37–46 (1994).
2. Whitmore RW, Immerman FW, Camann DE, Bond AE, Lewis RG, Schaum JL. Non-occupational exposures to pesticides for residents of two U.S. cities. Arch Environ Contam Toxicol 26:47–59 (1994).
3. Landrigan PJ, Claudio L, Markowitz SB, Berkowitz GS, Brenner BL, Romero H, Wetmur JG, Matte TD, Gore AC, Godbold JH, et al. Pesticides and inner-city children: Exposures, risks, and prevention. Environ Health Perspect 107(suppl 3):431–437 (1999).
4. Adgate JL, Barr DB, Clayton CA, Eberly LE, Freeman NCG, Lioy PJ, Needham LL, Pellizzari ED, Quackenboss JJ, Roy A, Sexton K. Measurement of children's exposure to pesticides: analysis of urinary metabolite levels in a probability-based sample. Environ Health Perspect 109:583–590 (2001).
5. Adgate JL, Kukowski A, Stroebel C, Shubat PJ, Morrell S, Quackenboss JJ, Whitmore RW, Sexton K. Pesticide storage and use patterns in Minnesota households with children. Expo Anal Environ Epidemiol 10:159–167 (2000).
6. Whyatt RM, Camann DE, Kinney PL, Reyes A, Ramirez J, Dietrich J, Diaz D, Holmes D, Perera FP. Residential pesticide use during pregnancy among a cohort of urban minority women. Environ Health Perspect 110:507–514 (2002).
7. Thier A, Enck J, Klossner C. Plagued by Pesticides: An Analysis of New York State's 1997 Pesticide Use and Sales Data. Albany, NY:Environmental Advocates, 1998.
8. Fenske RA, Black KG, Elkner KP, Lee CL, Methner MM, Soto R. Potential exposure and health risk of infants following indoor pesticide application. Am J Public Health 80:689–693 (1990).
9. Gurunathan S, Robson M, Freeman N, Buckley B, Roy A, Meyer R, Bukowski J, Lioy PJ. Accumulation of chlorpyrifos on residential surfaces and toys accessible to children. Environ Health Perspect 106:9–16 (1998).
10. Hill RH, Head SL, Baker S, Gregg M, Shealy DB, Bailey SL, Williams CC, Sampson EJ, Needham LL. Pesticide residues in urine of adults living in United States: reference range concentrations. Environ Res 71:99–108 (1995).
11. Macintosh DL, Needham LL, Hammerstrom KA, Ryan PB. A longitudinal investigation of selected pesticide metabolites in urine. J Expo Anal Environ Epidemiol 9:494–501 (1999).
12. Fenske RA, Lu C, Barr D, Needham L. Children's exposure to chlorpyrifos and parathion in an agricultural community in central Washington State. Environ Health Perspect 110:549–553 (2002).
13. Nolan RJ, Rick DL, Freshour NL, Saunders JH. Chlorpyrifos: pharmacokinetics in human volunteers. Toxicol Appl Pharmacol 73:8–15 (1984).
14. Leng G, Leng A, Kuhn KH, Lewalter J, Pauluhn J. Human dose-excretion studies with the pyrethroid insecticide cyfluthrin: urinary metabolite profile following inhalation. Xenobiotica 27: 1273–1283 (1997).
15. Uhl S, Schmid P, Schlatter C. Pharmacokinetics of pentachlorophenol in man. Arch Toxicol 58:182–186 (1986).
16. Chang MJW, Lin CY, Lo LW, Lin RS. Biological monitoring of exposure to chlorpyrifos by high performance liquid chromatography. Bull Environ Contam Toxicol 56:367–374 (1996).
17. Hill RH Jr, Shealy DB, Head SL, Williams CC, Sampson EJ, Needham LL. Determination of pesticide metabolites in human urine using an isotope dilution technique and tandem mass spectrometry. J Anal Toxicol 19:323–329 (1995).
18. Long G, Winefordner JD. Limit of detection. A closer look at the IUPAC definition. Anal Chem 55:712A–724A (1983).
19. Taylor JK. Guidelines for evaluating the blank correction. J Testing Eval 12:54–55 (1984).
20. Carrieri M, Trevisan A. Adjustment to concentration-dilution of spot urine samples: correlation between specific gravity and creatinine. Int Arch Occup Environ Health 74:63–67 (2001).
21. Boeniger MF, Lowry LK, Rosenberg J. Interpretation of urine results used to assess chemical exposure with emphasis on creatinine adjustments: a review. Am Ind Hyg Assoc 54:615–627 (1993).
22. Hornung RW, Reed LD. Estimation of average concentration in the presence of nondetectable values. Appl Occup Environ Hyg 5:46–51 (1990).
23. Dawson-Saunders B, Trapp RG. Basic and Clinical Biostatistics. Norwalk, CT:Appleton and Lange, 1990.
24. U.S. EPA. National Household Pesticide Usage Survey, 1976-1977. EPA 540/9-800-002. Washington, DC:Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, 1979.
25. Kutz FW, Cook BT, Carter-Pokras OD, Brody D, Murphy RS. Selected pesticide residues and metabolites in urine from a survey of the U.S. general population. J Toxicol Environ Health 37:277–291 (1992).
26. Seifert B, Becker K, Helm D. Krause C, Schulz C, Seiwert M. The German Environmental Survey 1990/1992 (GerES II); reference concentrations of selected environmental pollutants in blood, urine, hair, house dust, drinking water and indoor air. J Expo Anal Environ Epidemiol 10:552–565 (2000).
27. Heudorf U, Angerer J. Metabolites of pyrethroid insecticides in urine specimens: current exposure in an urban population in Germany. Environ Health Perspect 109:213–217 (2001).
28. Baker SE, Barr DB, Driskell WJ, Beeson MD, Needham LL. Quantification of selected pesticide metabolites in human urine using isotope dilution high-performance liquid chromatography/tandem mass spectrometry. J Expo Anal Environ Epidemiol 10:789–798 (2000).
29. New York City Department of Health. West Nile Virus Spray Schedules. Available: http://www.nyc.gov/html/doh/html/wnv/wnvspray.html [cited 7 November 2002].
30. Lu C, Knutson DE, Fisker-Andersen J, Fenske RA. Biological monitoring survey of organophosphorous pesticide exposure among preschool child in the Seattle metropolitan area. Environ Health Perspect 109:299–303 (2001).