

Residential Pesticide Use during Pregnancy among a Cohort of Urban Minority Women

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Residential pesticide use is widespread in the United States. However, data are limited specific to use among minority populations. Nor are data available on the extent of pesticide exposure resulting from residential use during pregnancy. We have gathered questionnaire data on pesticide use in the home during pregnancy from 316 African-American and Dominican women residing in northern Manhattan and the South Bronx. Additionally, 72 women underwent personal air monitoring for 48 hr during their third trimester of pregnancy to determine exposure levels to 21 pesticides (19 insecticides and 2 fungicides). Of the women questioned, 266 of 314 (85%) reported that pest control measures were used in the home during pregnancy; 111 of 314 (35%) reported that their homes were sprayed by an exterminator, and of those, 45% said the spraying was done more than once per month. Most ($\geq 90\%$) of the pesticide was used for cockroach control. Use of pest control measures increased significantly with the level of housing disrepair reported. Of the women monitored, all (100%) had detectable levels of three insecticides: the organophosphates diazinon (range, 2.0–6,010 ng/m³) and chlorpyrifos (range, 0.7–193 ng/m³) and the carbamate propoxur (range, 3.8–1,380 ng/m³), as well as the fungicide *o*-phenylphenol (range, 5.7–743 ng/m³). We also frequently detected the following four insecticides (47–83% of samples) but at lower concentrations: the pyrethroid *trans*-permethrin, piperonyl butoxide (an indicator of exposure to pyrethrins), and the organochlorines 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane and chlordane. Thirty percent of the women had detectable levels of all eight pesticides. Exposures were generally higher among African Americans than among Dominicans. We detected other pesticides in $\leq 10\%$ of samples. Results show widespread prenatal pesticide use among minority women in this cohort. Diazinon exposures for some women may have exceeded health-based levels, and our findings support recent federal action to phase out residential use of this insecticide.

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Residential pesticide use is widespread in the United States, with approximately 80–90% of American households using pesticides (1,2). Less persistent pesticides (organophosphates, carbamates, and pyrethroids) have replaced the older organochlorines for residential insect control (1). Commonly detected pesticides in house dust and indoor air of homes in the United States include the organophosphates chlorpyrifos and diazinon as well as the pyrethroids *cis*-permethrin and *trans*-permethrin and the carbamates propoxur and bendiocarb (2–4). It is likely that chlorpyrifos and diazinon will be detected less frequently in the future as a result of the recent regulatory actions by the U.S. Environmental Protection Agency (U.S. EPA) to phase out their residential use (5,6). Population-based surveys of pesticide urinary metabolites in adults and children also indicate widespread exposure to both organophosphate and carbamate insecticides, as well as to wood preservatives and fungicides (7–9). We know little about residential pesticide use among minority populations in the United States. Nor are data available on the extent of pesticide exposure among urban minority women

during pregnancy. Prenatal organophosphate exposure may be of particular concern because experimental studies in laboratory rodents have shown a link between exposures to several organophosphates, including chlorpyrifos and diazinon, during gestation or the early postnatal period and adverse neurodevelopmental sequelae in the offspring [reviewed by Landrigan et al. (1) and Eskenazi et al. (10)].

For the present study, we gathered information on pesticide use during pregnancy from 316 African-American and Dominican women residing in minority communities in New York City (Harlem, Washington Heights, and the South Bronx). In addition, a subset of the women underwent personal ambient air monitoring for 48 hr during their third trimester of pregnancy to determine exposure levels to 21 pesticides and/or their degradation products. We selected the pesticides based on results from prior residential air and dust monitoring and included the organophosphates commonly used for residential insect control (1). We present results for the total cohort and separately for African-American women

(residing predominantly in Harlem) and Dominican women (residing predominantly in Washington Heights). We also evaluated whether pesticide use and exposure varied across the three neighborhoods or varied with characteristics of the built environment, specifically the amount and type of housing disrepair. We undertook these latter analyses in anticipation that findings could assist in the development of community-specific interventions if needed.

Materials and Methods

The women included in this report are part of an ongoing prospective cohort study of African-American and Dominican women and their newborns being conducted by the Columbia Center of Children's Environmental Health. The center initiated the study in 1997 to evaluate the effects of prenatal exposures to ambient air pollutants (polycyclic aromatic hydrocarbons and environmental tobacco smoke) on birth outcomes and neurocognitive development among a cohort of mothers and newborns from minority communities in New York City. In 1998, the study also began to gather information on prenatal pesticide use in response to growing concerns over the extent of residential insecticide use in New York City (11). A total of 316 women have been enrolled into the cohort since the study began to gather information on prenatal pesticide use. Results on these 316 women are the subject of this report.

Enrollment. We recruited women into the study during pregnancy through the prenatal clinics at New York Presbyterian and Harlem hospitals. We told the women that the purpose of the research was to gather

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information on the effects of environmental exposures during pregnancy on asthma and child development. We restricted recruitment to women 18–35 years of age who had resided in northern Manhattan (Central Harlem or Washington Heights/Inwood) or the South Bronx for ≥ 1 year before pregnancy. To maximize study power, we also restricted recruitment to the two major ethnic groups in the study area and included women who self-identified as either African American or Dominican. Births among these two ethnic groups account for approximately 54% of births in Central Harlem, 46% in Washington Heights, and 52% in the South Bronx (12). To control for known risk factors of adverse birth outcomes, we excluded women if they smoked cigarettes or used other tobacco products or illicit drugs during pregnancy, if they had diabetes, hypertension or known HIV, or if they had had their first prenatal visit after the 20th week of pregnancy. Of the women who have been screened, 870 of 1,706 (47%) met these eligibility criteria, of whom 70% agreed to participate. Compared with those women who refused, women who agreed to participate were somewhat younger (24 ± 4.9 vs. 25.4 ± 5.4 years, $p = 0.06$, t -test), and a higher proportion were African American (44% vs. 39%, $\chi^2 = 1.2$, $p = 0.3$). Women were fully enrolled into the study once the prenatal monitoring and questionnaires had been completed and blood samples (from the mother and/or newborn) had been collected at delivery. The Institutional Review Board of the Columbia Presbyterian Medical Center approved the study, and we obtained informed consent from all study subjects.

Questionnaire data. A 45-min questionnaire was administered to each woman in her home by a trained research worker during the

third trimester of pregnancy. It included information on demographics, home characteristics, lifetime residential history, history of active and passive smoking, occupational history, alcohol and drug use during pregnancy, and history of residential pesticide use. The information on pesticide use included whether or not she had sighted pests (including cockroaches, rodents, and other pests) in the home during pregnancy and the frequency of pest sightings. We also asked the women whether any pest control measures were used in the home during pregnancy by an exterminator or by others (the woman, other household members, or the building superintendent). If pest control measures were used, we asked the women about the following eight specific types of methods: sticky traps, bait traps, boric acid, gels, spray by an exterminator, can sprays, pest bombs, and any other methods. Questions included whether or not the method had been used, and if so, how frequently it was used, and for which type of pest it was used. Information on the use of one or more of the specific methods was not available for 35 of the 266 women who said that pest control measures were used in the home during pregnancy (Table 1). Questions on housing included the physical integrity of walls, floors, and ceilings and the adequacy of the heating supply.

Personal ambient air monitoring. During their third trimester of pregnancy, we asked all women in the cohort to wear a small backpack holding a personal ambient air monitor during the daytime hours for 2 consecutive days and to place the monitor near the bed at night. The personal air sampling pumps operated continuously at 4 liters per minute over this period, collecting particles of ≤ 2.5 μm in diameter on a precleaned

quartz microfiber filter, and semivolatile vapors and aerosols on a polyurethane foam plug backup. We drew an average of 11.5 m^3 of air through the sampler. We analyzed the personal air monitoring samplers from all women in the cohort for polycyclic aromatic hydrocarbons, and results will be published elsewhere (13). In addition, in a range-finding study, we analyzed the air samples from a subset ($n = 72$) of the women for levels of 21 pesticides and/or their degradation products. We included in this pesticide subset study all the women monitored between September 1998 and August 1999 and who were fully enrolled by November 1999. By chance, the proportion of African-American women who were monitored for this substudy was higher than that in the total cohort, but the difference was not statistically significant (Table 1). Among these 72 women, the proportion who report that pest control measures were used in the home during pregnancy is similar to the proportion of women reporting use of pest control measures in the full cohort ($\chi^2 = 0.05$, $p = 0.8$).

For quality control, we coded each personal monitoring regarding accuracy in flow rate, time, and completeness of documentation. A code of 0 or 1 indicated no or minor problems; 2 indicated greater concern; and 3 indicated unacceptable and not analyzed. We coded one sample collected during the September 1998–September 1999 study period as 3 and did not include it in the results presented here. Two of the 72 women had personal air monitoring samples with a quality control code of 2; we performed statistical analyses both including and excluding code 2 subjects. Results were essentially unchanged from those that we present here for all 72 women.

Table 1. Demographics.

Characteristics	Total cohort ($n = 316$)	Sample ^a ($n = 266$)		Statistic ^c	Personal ambient air monitoring, 48 hr ($n = 72$)	Statistic ^d
		Complete data ^b ($n = 231$)	Incomplete data ^b ($n = 35$)			
Age	24.5 \pm 5.2	24.9 \pm 4.9	25.1 \pm 7.3	$p = 0.9$, t -test	24.2 \pm 5.2	$p = 0.3$, t -test
Ethnicity						
African American	136/316 (43%)	96/231 (42%)	15/35 (43%)	$\chi^2 = 0.02$, $p = 0.9$	38/72 (53%)	$\chi^2 = 2.5$, $p = 0.11$
Dominican	180/316 (57%)	135/231 (58%)	20/35 (57%)		34/72 (47%)	
Community						
Harlem	138/316 (44%)	99/231 (43%)	15/35 (43%)	$\chi^2 = 1.2$, $p = 0.5$	32/72 (44%)	$\chi^2 = 2.4$, $p = 0.3$
Washington Heights	110/316 (35%)	82/231 (35%)	15/35 (43%)		20/72 (28%)	
South Bronx	68/316 (22%)	50/231 (22%)	5/35 (14%)		20/72 (28%)	
Marital status						
Never married	220/315 (70%)	158/231 (68%)	24/34 (71%)	$\chi^2 = 0.07$, $p = 0.8$	53/71 (75%)	$\chi^2 = 0.9$, $p = 0.3$
Education						
< High school	103/315 (33%)	68/230 (30%)	13/35 (37%)	$\chi^2 = 0.8$, $p = 0.4$	24/72 (33%)	$\chi^2 = 0.01$, $p = 0.9$
Annual household income						
< \$10,000	135/303 (45%)	95/220 (43%)	16/34 (47%)	$\chi^2 = 0.2$, $p = 0.7$	31/72 (44%)	$\chi^2 = 0.06$, $p = 0.8$
Medical recipient	279/316 (88%)	204/231 (88%)	33/35 (94%)	$\chi^2 = 1.1$, $p = 0.3$	63/72 (88%)	$\chi^2 = 0.0$, $p = 1.0$

Age is reported as mean \pm SD; other data are number of subjects (%) in each category.

^aWomen reporting that pest control measures were used during pregnancy. ^bData on eight specific measures. ^cComparing women with complete versus incomplete data on the eight specific pest control methods. ^dCompared with the women in the total cohort without prenatal monitoring for pesticide levels; analyses included the 68 women with air monitoring results for whom we also collected questionnaire data on use of pest control methods in the home.

Pesticides in air monitoring samples. Immediately after collection, the air monitoring samples were brought to the molecular epidemiologic laboratory at the Mailman School of Public Health, inventoried, and frozen. Once each month, we shipped air monitoring samples on ice to Southwest Research Institute, where they were then stored at -12°C . Within 10 days of arrival at the institute, we placed the polyurethane foam plug and filter in a Soxhlet extractor (Corning, Corning, NY), which we spiked with terphenyl-d14 as a recovery surrogate, and extracted with 6% diethyl ether in hexanes for 16 hours, then concentrated the extractant to 1 mL. We froze extracts at -12°C before analysis. The pesticides for which we report air concentrations are stable in the extract under these conditions (14,15). We held each extract until after that woman delivered and analyzed it once the woman was fully enrolled in the study. We analyzed the extracted samples from the 72 women in batches between 5 and 20 November 1999. We passed the extract through a glass column (Burdick & Jackson, Muskegon, MI) that was packed with 1 g Florisil (Aldrich, Milwaukee, WI). We brought initial extracts to a concentration of 0.5 mL in 10% ether in hexanes. We brought subsequent extracts to a concentration of 1.0 mL to reduce interference from coeluting compounds. Because of the 2-fold variability in extract concentration, the analyte detection limits varied 2-fold. We determined the amounts of the target pesticides in samples using an Agilent 6890 gas chromatograph/5973 mass spectrometer (Agilent Technologies, Palo Alto, CA) as described previously (16). We injected cleaned extracts into a 30 m \times 0.25 mm inner-diameter DB-5.625 gas chromatography analytical column (J & W Scientific, Folsom, CA), and scanned the gas chromatography/mass spectrometry instrument to monitor two selected ions per analyte to achieve low-level detection. We performed quantification using deuterated polyaromatic hydrocarbons as internal standards (17). We

maintained the relative standard deviation of each analyte within 30% during the initial five-point standard calibration, and processed a continuing calibration standard at the beginning and end of each sequence of 15 extracts. We nearly always maintained the percent difference of each analyte in the mid-level standard within 40% of the initial calibration value during continuing calibrations, with slight exceptions flagged as calibration drift. Drift averaged $\leq 10\%$ and never exceeded 31% for any of the eight pesticides or their degradation products that are the main subjects of this report. The nominal analyte detection limit was one third the analyte level in the lowest standard of the initial five point calibration curve (i.e., 2–7 ng/combined air sample).

For several samples, interfering compounds coeluted with the analyte and elevated the detection limit. We flagged the result for these samples. In cases in which the interfering peak raised the detection limit but we did not detect the analyte, we considered the analytic result to be below the limit of detection only if the quantified peak was within 4-fold of the nominal detection limit for that analyte. If the interfering peak raised the detection limit to > 4 -fold for that analyte, we coded the result as missing. We considered this approach appropriate because the laboratory methodology was adequately sensitive to detect the analyte at 25% of the interference peak in all cases. Confirmation analyses have shown that the analyte represents 25–90% of the combined peak when both the analyte and an interfering compound were determined to coelute. In these cases, we quantified the entire peak and reduced the quantified amount by 50% to estimate the true analyte amount. We made this adjustment to 59 of 1,748 (3%) of the pesticide results, which affected mainly results for piperonyl butoxide (40 of 71 results adjusted).

Statistical analyses. We used chi-square analyses to test whether the proportion of women using pest control measures was

related to pest sightings in the home. We present the range in air concentration and the number of samples with levels above the limit of detection for the 21 pesticides or their degradation products measured in the personal air samples. We also present the medians, means, and standard deviations for the eight pesticides (or their degradation products) that we detected in $> 45\%$ – 100% of the personal air samples. For these pesticides, in air samples in which we did not detect the pesticide, we set levels to one-half the detection limit. We also restricted statistical analyses to these eight pesticides. Before the statistical analyses, we log-transformed levels of the eight pesticides to normalize positively skewed distributions. We used Pearson's correlation coefficient to examine associations between pesticide levels, and logistic regression to assess the association between dichotomous outcomes variables (whether or not pests were seen in the home or pest control measures used) and the following predictor variables: ethnicity, neighborhood of residence (Harlem, Washington Heights, or South Bronx), and level of housing disrepair. We used multiple linear regression to assess the association between continuous outcome variables (air levels of the eight pesticides) and the same predictor variables. We defined housing disrepair as the total number of adverse indoor housing problems reported, each indicator of disrepair being counted as present (1) or absent (0). The indicators were as follows: holes in ceilings or walls, peeling or flaking paint, water damage, visible mold, leaking pipes, and lack of gas or electricity in past 6 months. Because ethnicity and neighborhood of residence were correlated, we assessed model stability by comparing the coefficient for ethnicity before and after the addition of neighborhood of residence; all models remained stable. We also used multiple linear regression to test for differences in air pesticide levels among women reporting that no pest control methods were used compared with the following three groups: use of lower toxicity pesticides only (sticky traps, bait traps, boric acid, and gels); use of can sprays and pest bombs (with or without the lower toxicity methods); and use of spraying by an exterminator (with or without the other methods). Results were considered significant at $p < 0.05$.

Results

Table 1 provides demographics *a*) for the total cohort and, separately, *b*) for the women reporting that pest control measures were used in the home during pregnancy and *c*) for the women who underwent personal air monitoring. Of the 136 African-American women in the cohort, 99 (73%)

Table 2. Number of women reporting sighting of pests and use of pest control measures in the home during pregnancy.

Sighting	Number/total	Percent
Total number with pest sightings	262/315	83
Sightings of cockroaches	207/315	66
Sightings of rodents (mice and rats)	168/315	53
Sightings of other pests ^a	99/314	32
Total number using pest control measures	266/314	85
By an exterminator plus others ^b	88/314	28
By an exterminator only	23/314	7
By others only ^b	155/314	49

Data on sightings of cockroaches and rodents were missing for one woman, and data on other pests were missing for two women; data on pest control measures were incomplete for two women: one reported exterminator use but was unsure about use of other pest control methods by others; the other reported use of pest control methods by others but was not sure about exterminator use.

^aAnts, fleas, waterbugs, silverfish, bedbugs, and bees. ^bThe woman herself, other household members, or the apartment superintendent.

resided in Harlem, 6 (4%) resided in Washington Heights, and 31 (23%) resided in the South Bronx. Of the 180 Dominican women in the cohort, 104 (58%) resided in Washington Heights, 39 (22%) resided in Harlem, and 37 (20%) resided in the South Bronx. A total of 188 (60%) of the women in the cohort reported one or more housing problems: 42% reported peeling or flaking

paint, 31% reported holes in ceilings or walls, 21% reported water damage, 22% reported leaking pipes, 17% reported visible mold, and 7% reported lack of gas or electricity in past 6 months. Thirty-five women (11%) reported 4 or more problems. The level of housing disrepair reported did not differ significantly between African-American and Dominican women ($\chi^2 = 0.8, p = 0.9$) or among women residing in Harlem, Washington Heights, or the South Bronx ($\chi^2 = 4.2, p = 0.7$).

Table 2 shows the number of women reporting that pests (cockroaches, rodents, and other) were sighted in the home during pregnancy. The table also shows the number of women reporting that some form of pest control method was used in the home during pregnancy. Pest control measures (including exterminators) use in the home was reported by 238 of 260 (92%) of the women who reported that pests were sighted in the home, compared with 27 of 53 (51%) of the women who reported that no pests were sighted, a difference that was highly significant ($\chi^2 = 55.9, p < 0.001$).

For the users of pest control methods, Figure 1 shows the percentage of women reporting use of each of eight specific methods. To evaluate the relative frequency of use of each method, we restricted these analyses to the 231 of 266 women who reported pest control use who also provided complete data on all eight specific methods. Demographics on the 231 women with complete data did not differ significantly from the remaining 35 who were missing data on one or more methods (Table 1). Figure 1 also shows the proportion of each of the pest control methods that targeted cockroaches, rodents, or other pests. Sticky traps were the most common method used. Gels were the next most common method, and spray by an exterminator was the third most common method.

The other methods used in descending order were bait traps, can sprays, boric acid, and pest bombs. In addition, 9% of users reported the use of other miscellaneous methods, including the illegal “street pesticides” Tempo (the pyrethroid cyfluthrin, used for cockroach control) and Tres Pasitos (the carbamate aldicarb, used for rodent control) (1). Sixty-five percent of the women reported using more than one method. Seventy-nine percent of sticky trap use targeted rodents. The miscellaneous other methods were split fairly evenly (47–53%) between rodent and cockroach control. The vast majority ($\geq 90%$) of all the other methods targeted cockroaches. Very few of the methods targeted pests other than rodents and cockroaches. Fifty-four percent of can sprays users, 50% of boric acid users, 48% of sticky trap users, and 45% of exterminator users reported that these methods were used in the home once a month or more (data not shown). The other methods were used less frequently.

Table 3 shows results of the logistic regression analyses, with significant findings noted by asterisk. Controlling for ethnicity and neighborhood of residence, the proportion of women reporting that pests were sighted in the home and the proportion reporting that pest control measures were used in the home during pregnancy increased significantly with the level of housing disrepair reported. Among women with the highest disrepair, the odds ratio that pests were sighted in the home was 58 [95% confidence interval (CI), 9.1–378.3] and the odds ratio that pest control measures were used in the home was 6 (95% CI, 1.3–27.2). After controlling for level of housing disrepair, we found no significant differences between African-American and Dominican

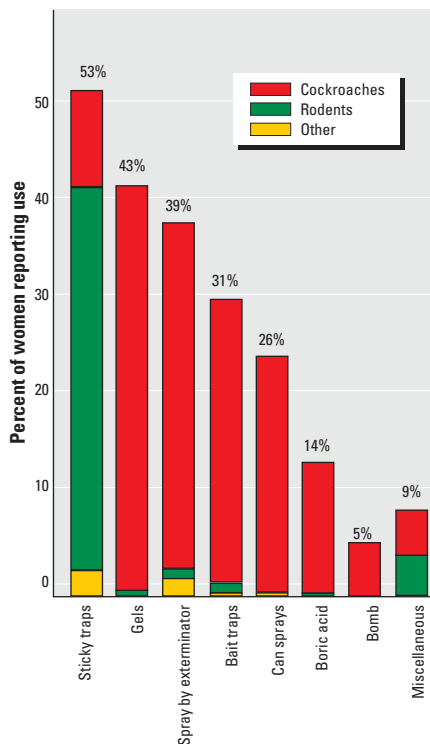


Figure 1. Percentage of pest control methods used and target pests for women who reported that pest control measures were used in their homes during pregnancy. Analyses included 231 of 266 women who reported use of pest control methods for whom data on all eight specific methods were complete.

Table 3. Logistic regression models of the association between dichotomous outcome variables (whether or not pests were sighted or pest control measures used) and housing disrepair, ethnicity, and neighborhood of residence.

	Housing disrepair ^a			Ethnicity ^b			Neighborhood of residence					
							Harlem vs. Washington Heights ^c			Harlem vs. South Bronx ^d		
	OR	95% LCL	95% UCL	OR	95% LCL	95% UCL	OR	95% LCL	95% UCL	OR	95% LCL	95% UCL
Any pests sighted	2.0*	1.4*	2.7*	0.9	0.4	1.9	0.8	0.3	1.9	0.8	0.4	1.9
Cockroaches sighted	1.3*	1.1*	1.6*	1.0	0.6	1.8	0.7	0.3	1.3	0.9	0.5	1.7
Rodents sighted	1.6*	1.3*	1.9*	0.5*	0.3*	0.96*	1.5	0.8	2.9	1.5	0.8	2.9
Any pest control measures used	1.4*	1.1*	1.7*	0.9	0.4	1.8	1.2	0.5	3.0	0.8	0.4	1.8
Specific measures (users only ^e)												
Sticky traps	1.3*	1.1*	1.5*	0.7	0.4	1.4	1.7	0.8	3.3	2.2*	1.1*	4.3*
Gels	1.0	0.9	1.2	0.4*	0.2*	0.8*	1.9	0.9	3.7	1.4	0.7	2.8
Spray by exterminator	0.9	0.8	1.1	0.7	0.4	1.3	0.3*	0.2*	0.7*	0.9	0.4	1.7
Bait traps	1.1	0.9	1.3	1.2	0.6	2.3	1.0	0.5	2.2	1.9	0.9	3.7
Can sprays	1.2	1.0	1.4	4.0*	1.9*	8.5*	1.3	0.6	3.0	0.5	0.2	1.2
Boric acid	1.3*	1.0*	1.6*	4.8*	1.7*	13.9*	1.4	0.5	4.5	0.5	0.2	1.6
Pest bombs	1.2	0.8	1.7	1.2	0.3	4.3	0.4	0.1	2.1	0.5	0.1	2.4
Miscellaneous	1.1	0.9	1.5	0.7	0.3	1.9	0.8	0.2	2.6	2.4	0.8	6.6

Abbreviations: LCL, lower confidence limit; OR, odds ratio; UCL, upper confidence limit.

^aTotal number of adverse indoor housing problems; OR is for each one unit increase in the levels of disrepair (0–6). ^bDominican = 0 and African American = 1. ^cHarlem = 0 and Washington Heights = 1. ^dHarlem = 0 and South Bronx = 1. ^eAmong the 231 users of pest control methods who provided complete data on all eight specific methods. * $p < 0.05$.

women or among women residing in Harlem, Washington Heights, or the South Bronx in the proportion reporting that cockroaches were seen in the home or the proportion reporting that some form of pest control measure was used in the home during pregnancy (Table 3). Dominicans were more likely than African Americans to report sighting rodents in the home.

When we restricted analyses to only those women who reported use of pest control methods (Table 3), we found several differences in the types of methods used associated with ethnicity and neighborhood of residence. Specifically, African-American women were significantly less likely than Dominicans to report using gels but were significantly more likely to report using can

sprays and boric acid. After controlling for ethnicity, Harlem residents were significantly more likely than residents of Washington Heights to report using an exterminator and were significantly less likely than women residing in the South Bronx to report using sticky traps. Use of sticky traps was also significantly associated with the level of housing disrepair.

Table 4. Air concentrations of 21 pesticides (or degradation products) over 48 hr of personal ambient air monitoring during the third trimester of pregnancy among 72 African-American and Dominican women from northern Manhattan and the South Bronx.

Pesticides	Detection limits ^a	No. above detection/total samples (%)	Air concentration (ng/m ³)		
			Median	Mean ± SD ^b	Range
Organophosphates					
Chlorpyrifos	0.2	72/72 (100)	9.9	21.1 ± 30.2	0.7–193
Diazinon	0.2	71/71 (100) ^c	24.5	159 ± 723	2.0–6,010
Methyl parathion	0.2	2/53 (4) ^c	ND	NC	ND–0.9
Dichlorvos	0.3	1/55 (2) ^c	ND	NC	ND–2.8
Malathion	0.2	0/49 (0) ^c	ND	NC	
Carbamates					
Propoxur	0.2	72/72 (100)	33.1	85.1 ± 198	3.9–1,380
Carbaryl	0.4	1/60 (2) ^c	ND	NC	ND–0.7
Pyrethroids					
Piperonyl butoxide ^d	0.1	59/71 (83) ^c	0.5	1.1 ± 1.7	ND–11.1
Permethrin					
<i>trans</i> -Permethrin	0.1	29/62 (47) ^c	ND	0.8 ± 1.3	ND–7.0
<i>cis</i> -Permethrin	0.4	24/72 (33)	ND	NC	ND–2.8
Cyfluthrin	0.6	7/72 (10)	ND	NC	ND–14.2
Organochlorines					
DDT					
4,4'-DDT	0.1	49/72 (68)	0.3	0.4 ± 0.6	ND–4.0
4,4'-DDE	0.1	47/72 (68)	0.2	0.4 ± 0.4	ND–2.2
Chlordane					
γ-Chlordane	0.2	56/72 (78)	0.3	0.4 ± 0.4	ND–2.5
α-Chlordane	0.2	42/72 (58)	0.1	0.2 ± 0.3	ND–1.8
<i>trans</i> -Nonachlor	0.3	9/72 (13)	ND	NC	ND–0.7
Heptachlor	0.2	0/72 (0)	ND	NC	
Lindane	0.5	1/44 (2) ^c	ND	NC	ND–3.2
Methoxychlor	0.2	1/70 (1) ^c	ND	NC	ND–0.5
Aldrin	0.7	0/71 (0) ^c	ND	NC	
Dicofol	0.6	0/67 (0) ^c	ND	NC	
Dieldrin	0.8	0/71 (0) ^c	ND	NC	
Endosulfan	0.4	0/72 (0)	ND	NC	
Endrin	0.7	0/72 (0)	ND	NC	
Fungicides					
<i>o</i> -Phenylphenol	0.6	72/72 (100)	23.7	35.3 ± 85.8	5.7–743
Folpet	0.2	1/68 (1) ^c	ND	NC	ND–1.1

Abbreviations: NC, not calculated; ND, not detected.

^aUpper limit of detection (ng/m³); detection limits varied depending of the concentration of the extract and the amount of air sampled over the 48 hours. ^bMean ± standard deviation (SD) was calculated if the pesticide was detected in > 45% of samples; levels in samples without detections were set at one half of the detection limit. ^cAir concentration could not be calculated for remaining sample(s) because of interference peaks. ^dNot itself a pyrethroid, but is an adjuvant and indicator of exposure to pyrethrins.

Table 5. Correlations^a among the eight pesticides or their degradation products detected in ≥ 47% of the air monitoring samples over 48 hr of personal monitoring of African American and Dominican women during the third trimester of pregnancy.

	<i>o</i> -Phenylphenol	α-Chlordane	γ-Chlordane	DDE	DDT	<i>trans</i> -Permethrin	Piperonyl butoxide	Propoxur	Diazinon
Chlorpyrifos	0.09	−0.02	−0.05	0.03	0.08	0.17	0.31*	0.17	0.18
Diazinon	0.08	0.11	0.03	0.11	0.11	0.41**	0.34*	0.36*	
Propoxur	−0.05	0.17	0.07	0.23	0.19	0.40**	0.57**		
Piperonyl butoxide	0.06	0.05	−0.02	0.09	0.18	0.67**			
<i>trans</i> -Permethrin	0.04	0.07	−0.001	0.03	0.17				
4,4'-DDT	−0.01	0.52**	0.57**	0.80**					
4,4'-DDE	−0.04	0.66**	0.69**						
γ-Chlordane	0.04	0.93**							
α-Chlordane	0.04								

^aPearson correlation (*r*) between log-transformed pesticide levels. * *p* < 0.01; ***p* ≤ 0.001.

can sprays and pest bombs, or spraying by an exterminator. We did not include *o*-phenylphenol in these analyses because it is a fungicide/disinfection product not used for pest control, and did not include DDT or chlordane because they are no longer in use legally in the United States. Air concentrations were generally higher among women reporting use of pest control measures. However, except for propoxur, the differences were not statistically significant.

Figure 3 shows the percentage of women with exposures to four or more of the eight pesticides sampled over the 48 hr of personal monitoring. We undertook the analyses to assess the degree to which women in the cohort were exposed to mixtures of pesticides during pregnancy. Analytic results for the eight pesticides combined were available for 60 women in the cohort. As shown in Figure 3, we detected all eight pesticides in the personal air samples of 30% of the women.

Table 6 provides results of the multiple linear regression analyses. Except for chlordane, African Americans had higher pesticide exposures than did Dominicans; the difference was significant for propoxur, piperonyl butoxide, and *trans*-permethrin, controlling for level of housing disrepair and neighborhood of residence. Diazinon, propoxur, and piperonyl butoxide also varied significantly between Harlem and one or both of the other two neighborhoods, controlling for ethnicity and housing disrepair. Air concentrations of *trans*-permethrin and γ -chlordane

were significantly associated with level of housing disrepair, controlling for ethnicity and neighborhood of residence.

Discussion

These results show widespread pesticide use and exposure during pregnancy among a cohort of African-American and Dominican women from minority communities of New York City. Specifically, 85% of the women report that pest control measures were used in the home during pregnancy, and we detected at least four pesticides in the personal air samples of all women monitored during the third trimester. The pesticides detected at the highest concentrations were the organophosphates diazinon and chlorpyrifos, the carbamate propoxur, and the fungicide *o*-phenylphenol.

Our findings are consistent with prior data showing widespread residential pesticide use nationwide, including chlorpyrifos and diazinon (1,18). Before the recent regulatory action to phase out residential uses of these two insecticides, the U.S. EPA has estimated that approximately 75% of U.S. diazinon use and 50% of U.S. chlorpyrifos use has been for residential pest control (5,6). The results are also consistent with 1997 data for New York State indicating that the heaviest application of legally registered pesticides occurred not in the agricultural communities but in the boroughs of Manhattan and Brooklyn (11). Chlorpyrifos was the pesticide most heavily applied throughout New York State

(11). The number of gallons of chlorpyrifos applied in Manhattan exceeded the total number of gallons of all pesticides applied in any other single county in the state. Similarly, chlorpyrifos has been one of the most heavily used insecticides by pest control operators for the New York City Housing Authority (1).

Few prior studies have conducted personal air monitoring of pesticide exposures, and no prior study has monitored personal exposures of urban minority women during pregnancy. However, these findings can be compared with those of the Non-occupational Pesticide Exposure Study (NOPES), which provided for 24-hr personal air monitoring of residents from two locations in the United States between 1986 and 1988: Springfield/Chicopee, Massachusetts (selected to represent an area with low household pesticide use), and Jacksonville, Florida (selected to represent an area with high household pesticide use) (2). Air concentrations of chlorpyrifos and propoxur seen here were lower than those found in Jacksonville, whereas diazinon levels were similar. Concentrations of all three pesticides were higher than those seen in Springfield/Chicopee. Air concentrations of the fungicide *o*-phenylphenol were similar across both NOPES study locations and the present study.

The U.S. EPA has recently initiated regulatory action to phase out residential use of both diazinon and chlorpyrifos (5,6). Results from the present study support this action.

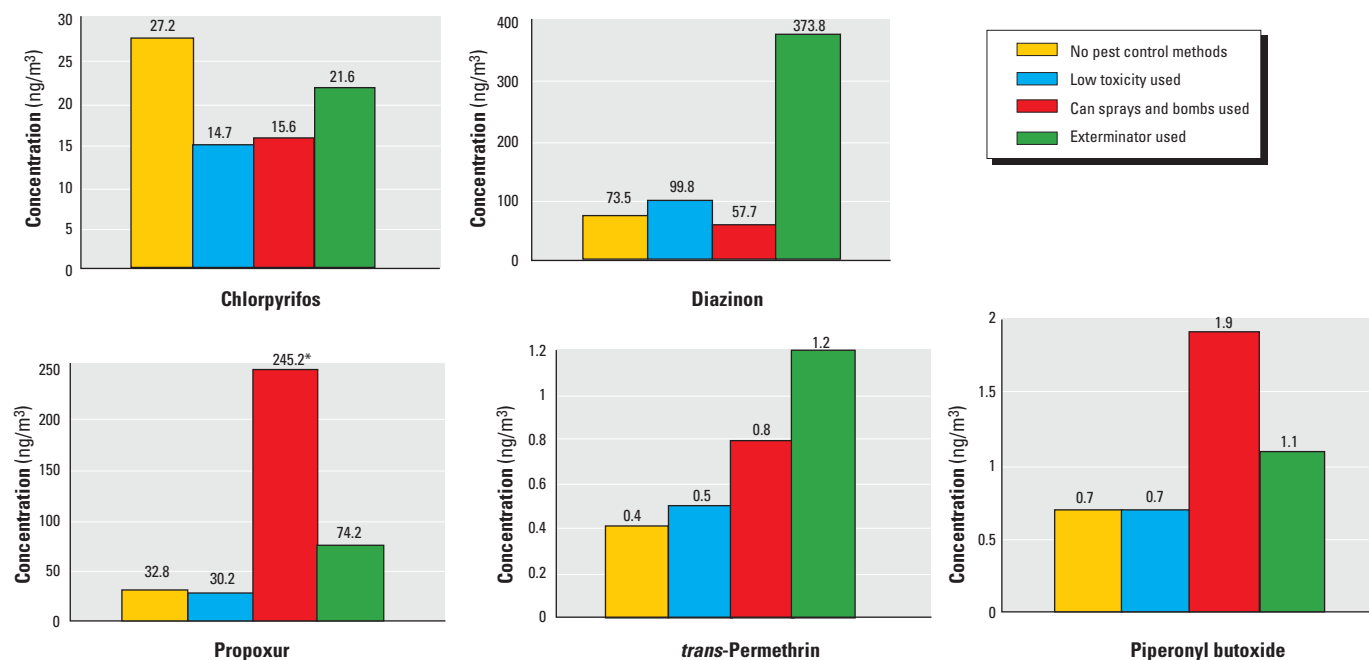


Figure 2. Mean air concentrations (ng/m^3) of five pesticides or metabolites during 48 hr of personal monitoring during the third trimester of pregnancy, among women not using pest control methods during pregnancy and women who used lower toxicity pesticides, can sprays and pest bombs, or spraying by exterminators. Analyses included the 68 women with air monitoring results for whom questionnaire data on use of pest control methods in the home was also collected.

* $p < 0.01$ versus women not using pest control methods.

In fact, it is possible that exposures for some women exceeded the recommended health-based level for diazinon (19). Specifically, the U.S. EPA has set a reference dose (RfD) of 0.00009 mg/kg/day for inhalation exposures to diazinon (of any duration) (19). Based on the U.S. EPA's assumptions regarding absorption and using its default inhalation volumes (15.2 m³/day) and body weight (70 kg) for adults (19), inhalation exposures to diazinon at the average concentration seen in the present study would be 38% of the diazinon RfD. At the 95th percentile concentration, exposures would be 80% of the RfD, and at the 99th percentile concentration, exposures would be 14 times the RfD. Exposures of young children breathing the same air as their mothers would be higher. For example, based on the U.S. EPA's default inhalation rate (8.7 m³/day) and body weight (15 kg) for a toddler (19), diazinon exposures at the average concentration would equal the RfD; at the 95th percentile concentration, exposures would be twice the RfD; and at the 99th percentile concentration, exposures would be 39 times the RfD.

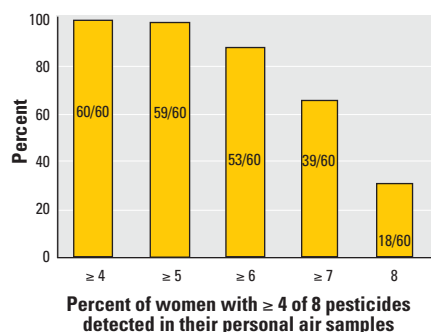


Figure 3. Percentage of women with four or more of the eight pesticides detected in their personal air over 48 hr of monitoring during the third trimester of pregnancy. The eight pesticides are chlorpyrifos, diazinon, propoxur, piperonyl butoxide, permethrin (*cis* and *trans*), DDT (including DDE), chlordane (including α -, γ -, and *trans*-nonachlor), and *o*-phenylphenol. Analytic results for the eight pesticides combined were available for 60 women in the cohort.

Further, it is possible that the aggregate exposures associated with the air concentrations seen in this study are greater than exposures from inhalation alone, because prior data indicate that exposure from residential pesticide use may also come through dermal absorption and nonintentional ingestion (2,19,20). This is supported by studies that have shown a high correlation ($r \geq 0.7$) between pesticide levels in indoor and personal air and those in carpet dust, hand wipes (including from mothers and children), and surfaces in the home (2,21,22), although uncertainty remains over the extent of exposure from these sources (23). In addition, chlorpyrifos and diazinon have similar mechanisms of action, and risks from chlorpyrifos exposure should thus be considered additive to those from diazinon exposure (24). Subjects may also receive some exposure to these pesticides through the diet. For example, chlorpyrifos residues were in 38% of the food samples collected over 4 days from 75 individuals (25), and dietary intakes of chlorpyrifos have been estimated to account for approximately 7% of chlorpyrifos metabolites in urine (26).

Experimental evidence in laboratory rodents has linked organophosphate exposure during gestation or the early postnatal period to adverse neurodevelopmental sequelae in the offspring [reviewed by Landrigan et al. (1) and Eskenazi et al. (10)]. Specifically, neurobehavioral effects have been seen experimentally following perinatal exposures to chlorpyrifos and diazinon, as well as dichlorvos, sumithion, and trichlofon (10). Organophosphate exposures have also been shown to inhibit brain acetylcholinesterase, downregulate muscarinic receptors, inhibit the adenylate cyclase signaling cascade, decrease brain DNA and RNA synthesis, and suppress neurite outgrowth (27–31). Recent evidence suggests that prenatal exposures may be more dangerous than previously thought, because acetylcholinesterase may have a direct role in neuronal differentiation

(27,30). However, no prior studies have assessed effects of prenatal organophosphate exposure on the developing human fetus, and we do not know whether the exposures at the pesticide concentrations seen in the present study, which are considerably lower than doses used in experimental bioassays, are associated with any adverse sequelae. We are following the newborns in this cohort, and the effects of prenatal exposures on their neurocognitive development will be assessed.

The present study found that the quality of housing was a significant predictor of both whether pests were sighted in the home and whether pest control measures were used. To our knowledge, this is the first study to assess the relationship between housing quality and use of pest control methods. However, other studies have found building design and management to be predictive of pest allergen levels (32,33). Housing quality has also been shown to be a significant predictor of cockroach allergen levels among women in the present cohort (34). Collectively, these findings have important implications for interventions [see Rauh et al. (34)]. In New York City, building maintenance is largely the responsibility of landlords, managing agents, and city agencies rather than individual tenants and is at least to some extent determined by public policy. In general, the quality of housing in these communities is poor (35), although housing varies substantially. Inadequate enforcement of city codes and inadequate repair of city properties have contributed to deteriorated housing stock (34). Communities also vary in political processes influencing the built environment (36,37). Historically, Harlem and the South Bronx have high rates of abandoned buildings (38) and of urban renewal efforts resulting in relocation (36). If pest problems, pesticide use, and allergen levels are all influenced by the quality of the built environment, policy changes and structural solutions may be important components of effective interventions.

Table 6. Multiple linear regression models of the association air concentrations of pesticides (ng/m³)^a with housing disrepair, ethnicity, and neighborhood of residence.

Pesticides	Housing disrepair ^b		Ethnicity ^c		Neighborhood of residence			
	β (SE)	<i>p</i> -Value	β (SE)	<i>p</i> -Value	Harlem vs. Washington Heights ^d		Harlem vs. South Bronx ^e	
					β (SE)	<i>p</i> -Value	β (SE)	<i>p</i> -Value
Chlorpyrifos	-0.1 (0.1)	0.17	0.4 (0.4)	0.3	0.5 (0.5)	0.3	0.3 (0.4)	0.5
Diazinon	-0.01 (0.1)	0.9	0.7 (0.5)	0.13	1.2* (0.6)*	0.04*	0.8 (0.5)	0.09
Propoxur	0.05 (0.07)	0.5	1.3* (0.3)*	< 0.001*	0.9* (0.4)*	0.02*	0.8* (0.3)*	0.01*
Piperonyl butoxide	0.06 (0.08)	0.4	1.6* (0.3)*	< 0.001*	0.7 (0.4)	0.07	0.9* (0.3)*	0.005*
<i>trans</i> -Permethrin	0.2* (0.1)*	0.03*	1.5* (0.4)*	0.001*	0.2 (0.5)	0.7	0.7 (0.4)	0.09
4,4'-DDT	0.02 (0.08)	0.8	0.4 (0.3)	0.2	0.4 (0.4)	0.3	0.4 (0.3)	0.3
4,4'-DDE	0.06 (0.07)	0.4	0.3 (0.3)	0.4	0.6 (0.4)	0.1	0.4 (0.3)	0.2
γ -Chlordane	0.13* (0.06)*	0.04*	-0.4 (0.3)	0.14	-0.05 (0.3)	0.9	0.17 (0.3)	0.6
α -Chlordane	0.13 (0.06)	0.05	-0.3 (0.3)	0.3	-0.07 (0.3)	0.8	0.2 (0.3)	0.5
<i>o</i> -Phenylphenol	0.01 (0.05)	0.8	0.4 (0.2)	0.1	0.1 (0.3)	0.7	0.4 (0.2)	0.1

^aPesticide levels were log-transformed before analyses. ^bTotal number of adverse indoor housing problems; β is for each one unit increase in the levels of disrepair (0–6). ^cDominican = 0 and African American = 1. ^dHarlem = 0 and Washington Heights = 1. ^eHarlem = 0 and South Bronx = 1. *Statistically significant results (see “Statistical Analyses”).

This study illustrates the challenge in conducting epidemiologic studies of residential pesticide use, because exposures generally involve complex mixtures rather than single compounds (2,18). In the present cohort, all women monitored were exposed to at least four of the eight pesticides assessed, and 30% of the women were exposed to all eight. Exposure levels for many of these pesticides were also correlated. Some of the pesticides in this mixture have similar mechanisms of action and/or similar toxicologic end points. For example, the organophosphates chlorpyrifos and diazinon, as well as the carbamate propoxur, are all acetylcholinesterase inhibitors. However, the pesticides are also associated with a diverse range of toxicities. In addition to being an acetylcholinesterase inhibitor, propoxur has recently been shown to be a tumor promoter (39). The pyrethroids are transient neurotoxins and skin and respiratory irritants (40,41). The organochlorines DDT and chlordane are neurotoxins and have been shown to be carcinogens and endocrine disruptors in experimental bioassays (42,43). *o*-Phenylphenol is a rat bladder carcinogen (44). How the pesticides in this mixture interact, and whether effects are additive, synergistic, or antagonistic, is not known. Results from this study indicate the need for additional research on the effects of residential use of pesticides (both singly and in combination) on the developing fetus.

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