

Abatement of cockroach allergen (Bla g 1) in low-income, urban housing: A randomized controlled trial

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Background: Clinically relevant reductions in exposure to cockroach allergen, an important risk factor for asthma in inner-city households, have proven difficult to achieve in intervention trials.

Objective: This study investigated a method for the abatement of cockroach allergen in low-income, urban homes. The goal was to reduce mean Bla g 1 concentrations below the previously proposed thresholds for allergic sensitization and asthma morbidity.

Methods: A prerandomized, nonmasked trial with 16 intervention and 15 control homes was conducted. Study inclusion was based on 50 to 500 cockroaches trapped in a 3-day period. The interventions consisted of occupant education, placement of insecticide bait, and professional cleaning. Vacuumed dust and multiple swab samples were collected at 0, 1, 2, 4, and 6 months in intervention homes and at 0 and 6 months in control homes. Room maps containing cockroach and allergen data were used to guide and monitor the interventions.

Results: From 0 to 6 months among intervention homes, geometric mean Bla g 1 concentrations (U/g dust) decreased from 633 to 24 on kitchen floors (96% reduction), from 25 to 4.3 on living room floors/sofas (83% reduction), from 46 to 7.3 on bedroom floors (84% reduction), and from 6.1 to 1.0 in bedroom beds (84% reduction). These reductions, with the exception of that on the bedroom floor ($P = .06$), were statistically significant relative to changes in control homes.

Conclusions: Substantial reductions in cockroach allergen levels can be achieved in inner-city homes. In this study, allergen

levels were reduced below the sensitization threshold (2 U/g) in beds, arguably the most relevant site for exposure, and below the asthma morbidity threshold (8 U/g) on bedroom floors and living room floors/sofas. The level on kitchen floors, although reduced 96%, remained above the asthma morbidity threshold. Future studies will test the intervention's effectiveness in asthma prevention trials. (*J Allergy Clin Immunol* 2003;112:339-45.)

Key words: Cockroaches, cockroach allergen, Bla g 1, intervention

Evidence suggests that exposure to cockroach allergen might be the most important risk factor for asthma in inner-city households. The National Cooperative Inner-City Asthma Study (NCICAS) found that asthma morbidity was highest in children with *both* a positive skin-test response and a high exposure (>8 U/g) to the cockroach allergen Bla g 1 in the bedroom.¹ Detectable levels of cockroach allergen were found in 85% of the bedrooms tested, and 50% of the bedrooms had levels >2 U/g, the proposed threshold for allergic sensitization.^{1,2} In a study of children in Boston, cockroach allergen exposure in the family room was a predictor of 2 or more episodes of wheeze in the first year of life.³ However, the risk of asthma from exposure to cockroach allergen is not limited to children. Indeed, a recently published study of elderly patients with asthma in New York City found that cockroach allergen sensitization was the most common sensitization (approaching 50%) and was associated with a greater degree of airflow obstruction and hyperinflation.⁴

These findings suggest that reducing exposure to cockroach allergen could be an effective strategy for improving the health among inner-city residents. However, cockroach extermination alone does not seem to be effective in lowering allergen levels,⁵ and there are no proven methods for allergen abatement in infested homes. Although several studies that combined cockroach extermination with cleaning demonstrated reductions in allergen levels,⁶⁻⁸ none was successful in lowering cockroach allergen levels below clinically relevant thresholds.

The objective of this study was to evaluate the efficacy of an intervention to abate cockroach allergen in low-income, urban homes. The goal was to reduce mean cock-

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Abbreviation used

NCICAS: The National Cooperative Inner-City Asthma Study

roach allergen levels below the thresholds for allergic sensitization and asthma morbidity. Once successful abatement methods have been identified, they will be used in future primary and secondary asthma prevention trials.

METHODS**Recruitment of homes**

The addresses of approximately 100 potentially eligible, cockroach-infested homes, all within the same metropolitan area of North Carolina, were obtained from a real estate management firm. Although these homes were drawn from a convenience sample, they were fairly typical of the low-income, multiunit housing found in many metropolitan areas of the Southeast. Homes were randomly assigned to an intervention or control group list and recruited in their listed order. Initial eligibility was established by a brief telephone interview of an adult occupant. Final eligibility was established by an in-home screening visit in which informed consent was obtained, study rooms were identified (kitchen, living room, and bedroom), cockroach traps were set, and the Home Environment Survey and Questionnaire (see <http://www.niehs.nih.gov/airborne/home.htm>) was administered. Six cockroach traps (Victor Roach Pheromone Traps; Woodstream, Lititz, Pa) were placed in each study room, collected 3 days later, and sent to the laboratory of a co-author for species identification and enumeration. Study eligibility was based on the following criteria:

1. An adult aged 21 years or older lived at the home full time.
2. The adult occupant intended to live at the same address for at least 6 months.
3. The adult occupant would be available at home during the study period.
4. The adult occupant provided informed consent.
5. Fifty to 500 cockroaches were trapped in a 3-day period.

The goal was to have 16 homes in each group complete the study. Forty-two intervention homes were contacted, of which 20 were ineligible. Twenty-two intervention homes were enrolled, 16 completed the study, and 6 were withdrawn either because the household moved or safety became an issue for the study staff. Forty-four control homes were contacted, of which 3 refused to participate and 24 were ineligible. Seventeen control homes were enrolled, 15 completed the study, and 2 were withdrawn either because the household moved or safety became an issue. This study was approved by The National Institute of Environmental Health Sciences Institutional Review Board.

Baseline allergen sampling

Baseline allergen sampling occurred approximately 1 week after the screening visit. Two methods of sampling were used in all homes: vacuuming and swabbing. A vacuumed dust sample was collected from each of the following locations: the kitchen floor, the living room floor and sofa (combined sample), the bedroom floor, and the bedroom bed. These samples were collected using a Eureka Mighty-Mite 7.0-ampere vacuum cleaner (Eureka Company, Bloomington, Ill). A 19 mm × 90 mm cellulose extraction thimble (Whatman International, Ltd., England) was placed in the distal end of the vacuum's extension tube, sealed with a rubber o-ring, and

covered with a clean crevice tool. The perimeter of the kitchen floor was vacuumed for 5 minutes. A 2-m² floor area in front of the living room sofa was vacuumed for 2.5 minutes, followed by a 2.5-minute vacuuming of the exposed surfaces of the sofa. A 2-m² area of the bedroom floor was vacuumed for 5 minutes. The bed was vacuumed for a total of 5 minutes—pillows for 1 minute, bedding layers for 2 minutes, and the mattress surface for 2 minutes. Fully encasing pillow or mattress covers, if present, were not removed.

Swab samples were collected at 20 locations within each study room (a total of 60 samples per home). Locations included floor surfaces, elevated surfaces, and cabinet shelves. At a given sample location, a 10 × 10-cm plastic template was placed on the surface. A cotton swab, which had been dampened in PBS containing 1% BSA and 0.05% Tween-20 detergent, was wiped over the 100-cm² surface for approximately 30 seconds and then placed in a 15-mL polypropylene tube containing 1 mL of buffer. The samples were transported the same day at ambient air temperature to The National Institute of Environmental Health Sciences laboratory.

At the laboratory, the swab samples—still in the 15-mL polypropylene tubes containing 1 mL of buffer—were placed on a rocking platform and extracted for 1 hour at room temperature. The buffer was removed from the swabs and clarified by centrifugation. Supernatants were aliquoted and stored at −20°C. Vacuumed dust samples were sieved through 425-μm pore grating, weighed, and divided into 50-mg aliquots of fine dust. Dust aliquots were extracted in PBS and clarified by centrifugation. Supernatants were decanted and stored at −20°C. Concentrations of Bla g 1 were measured with a monoclonal antibody–based enzyme-linked immunosorbent assay⁹ and reported as units of allergen/100 cm² of surface area (U/100 cm²) for swab samples and units of allergen per gram of dust (U/g) for vacuumed dust samples. Lower levels of detection were 0.005 U/100 cm² for swab samples and 0.1 U/g for vacuumed dust samples.

Layout maps

A 2-dimensional layout map of each study room (Fig 1), which incorporated details such as floor dimensions, doorways, and major furniture and appliance items, was hand drawn at the screening visit and then converted to an electronic format using Canvas Version 7.0. All cockroach trapping and allergen sampling locations were recorded on the maps, along with location-specific cockroach counts and allergen concentrations. An updated map was generated for each follow-up visit. These maps served 3 purposes: (1) to allow for repeated trapping and sampling of the same locations, (2) to guide interventions, and (3) to monitor allergen reductions.

Initial interventions

Interventions began approximately 1 week after baseline sampling and consisted of occupant education, insecticide application, and professional house cleaning. The goal of the interventions was to eradicate cockroaches and to reduce cockroach allergen concentrations to below the clinically relevant thresholds. Occupants were provided information about the causes of cockroach infestation and ways to prevent infestation, such as eliminating food/water sources and harborage/entry points within their homes. Occupants were also provided with a new vacuum cleaner (Eureka Model 4675) and asked to vacuum weekly.

Before insecticide application, professional cleaners thoroughly cleaned each intervention home. All hard-surfaced floors, walls, and ceilings were vacuumed and wiped down with diluted bleach or mild detergent and frequently changed cotton cloths. Surfaces of furniture, appliances, cabinets, and fixtures were wiped down. Kitchen cabinets and drawers were emptied, vacuumed, and wiped down. Trash was emptied, clutter was removed, and all uncovered food items were placed in sealed containers. Carpets were vacuumed and then cleaned

TABLE I. Baseline characteristics of control and intervention homes

Characteristic*	Control (n = 15)	Intervention (n = 16)
Dwelling/household		
Multiunit dwelling	15	16
Median (min, max) number of rooms in home	4 (2, 4)	4 (2, 5)
Median (min, max) number of people in household	5 (3, 11)	6 (4, 8)
Homes with children <18 y	10	14
Homes with income <\$30,000†	10	9
Homes with poor housekeeping‡	6	8
Homes in fair or poor condition§	14	16
Cockroach activity		
Homes with cockroach stains observed in any room	14	15
Homes with living cockroaches observed in any room	12	10
Homes with dead cockroaches observed in any room	11	10
Homes that used off-the-shelf products for roach control	11	10
Homes that used an exterminator in past month	0	1
Median (min, max) number of cockroaches trapped	318 (108, 459)	311 (86, 530)

*There were no significant differences between the control and intervention homes.

†Only 12 control and 9 intervention households provided income information.

‡No recent cleaning, lack of organization, greasy cooking area, and clutter.

§At least 1 score of fair or poor for walls and ceilings, floors, or windows.

vacuum and swab samples, changes from baseline to 6 months of the log₁₀-transformed concentrations were analyzed using a linear model in SAS Proc GLM (Cary, NC), with baseline allergen levels included in the model as the only covariate. Statistical significance from a 2-sided test was set at $P \leq .05$. Analyses were performed only on homes that completed the study.

RESULTS

Baseline housing characteristics

The intervention and control homes had similar baseline characteristics, as shown in Table I. Evidence of cockroach activity, such as live and dead cockroaches and cockroach stains, was observed in most of the homes. Although most households had used pesticides, sprays, or traps to rid their homes of cockroaches, only 1 household reported the use of a professional pest exterminator in the previous month. The median number of cockroaches trapped at baseline was similar for control and intervention homes.

Distribution and reduction of cockroaches

Among all intervention and control homes combined, the median (minimum, maximum) number of cockroaches trapped at baseline was 137.5 (38, 347) in kitchens, 60.0 (3, 204) in living rooms, and 37.0 (1, 311) in bed-

rooms. All cockroaches were of the German cockroach, *Blattella germanica*. Table II shows the median cockroach counts by group assignment, visit, and location. Among intervention homes, large reductions in numbers of trapped cockroaches were observed by month 1, and by month 6, the median count was 0 in each room. The number of intervention homes with no trapped cockroaches increased steadily at each visit. By month 6 in the intervention homes, 9 kitchens, 11 living rooms, and 12 bedrooms had trap counts of 0, and 6 of the 16 homes had no trapped cockroaches in any room.

Among control homes, the median count also decreased in each room from baseline to month 6; however, only 2 kitchens, 4 living rooms, and 3 bedrooms had trap counts of 0 at month 6, and only 1 of the 15 control homes had no trapped cockroaches in any room.

Distribution and reduction of cockroach allergen

Vacuum sampling results. Consistent with the high number of cockroaches trapped in kitchens at baseline, kitchens (all homes combined) had the highest geometric mean Bla g 1 concentration (U/g) in vacuumed dust (475.8; 95% CI, 279.9-809.1), followed by bedroom floors (28.7; 16.0-51.7), living room floors/sofas (26.4; 18.8-37.1), and bedroom beds (5.5; 3.7-8.2).

Fig 2 shows the vacuumed dust Bla g 1 concentrations by group assignment and visit month for each of the 4 sample locations. The reference lines at 2 and 8 U/g mark the previously proposed thresholds for allergic sensitization and asthma morbidity, respectively.^{1,2} On kitchen floors of intervention homes, the geometric mean Bla g 1 concentration declined from 632.9 at baseline to 23.9 at month 6, a 96% reduction. An 84% reduction occurred within the first month. In contrast, the reduction among the control homes was only 18%, and relative to control homes, the 6-month allergen reduction in intervention homes was statistically significant ($P = .002$). At month 6 in intervention homes, 2 kitchens had allergen levels below the sensitization threshold, and 5 had levels below the asthma morbidity threshold.

On living room floors/sofas of intervention homes, the geometric mean Bla g 1 concentration decreased from 24.9 at baseline to 4.3 at month 6, an 83% reduction. A 59% reduction occurred by month 1. The 6-month allergen reduction among intervention homes was significant ($P < .0001$) relative to control homes, which showed essentially no change. At month 6 in intervention homes, 3 living room floors/sofas had allergen levels below the sensitization threshold, and 12 had levels below the asthma morbidity threshold.

On bedroom floors of intervention homes, the geometric mean Bla g 1 concentration declined from 46.3 at baseline to 7.3 at month 6, an 84% reduction. A 65% reduction occurred within the first month. Although the geometric mean in control homes increased from baseline to 6 months by 54%, the 6-month allergen reduction in intervention homes was not statistically significant ($P = .06$) relative to control homes. At month 6 in interven-

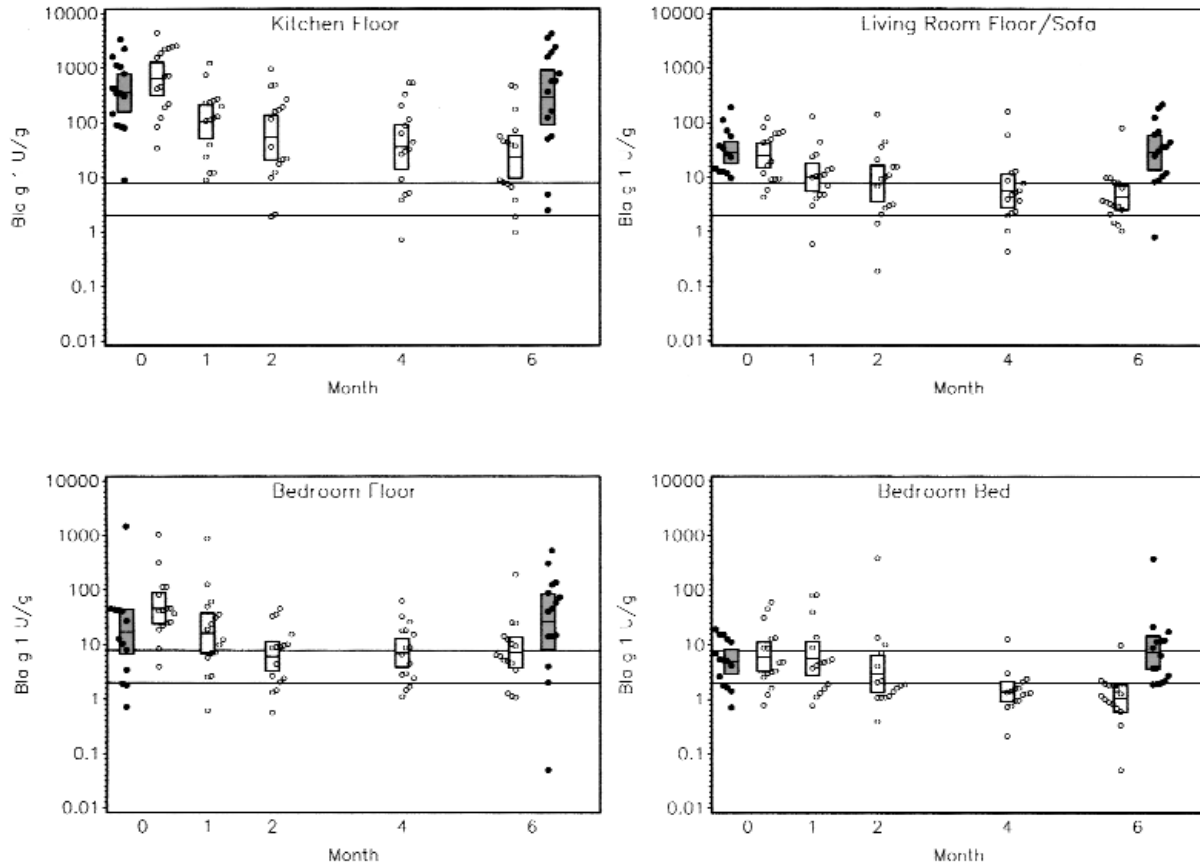


FIG 2. Bla g 1 allergen concentrations from vacuumed dust samples. Box plots show geometric means and 95% CIs for control (*shaded*) and intervention (*open*) homes. Circles represent individual homes. Lines at 2 U/g and 8 U/g show proposed thresholds for allergic sensitization and asthma morbidity, respectively.

Environmental and occupational disorders

TABLE II. Median (minimum, maximum, homes with 0) cockroach trap counts by group assignment, month of visit, and trap location

Group assignment	Month	Trap location		
		Kitchen	Living room	Bedroom
Intervention (n = 16)	0	113.0 (38, 287, 0)	76.0 (3, 204, 0)	78.0 (0, 311, 1)
	1	11.5 (0, 164, 1)	2.0 (0, 67, 4)	1.0 (0, 47, 6)
	2	2.0 (0, 138, 5)	0.5 (0, 32, 8)	0.0 (0, 24, 11)
	3	2.0 (0, 88, 5)	0.0 (0, 106, 9)	0.0 (0, 17, 9)
	4	1.0 (0, 119, 7)	0.0 (0, 3, 9)	0.0 (0, 12, 10)
	5	0.5 (0, 39, 7)	0.0 (0, 44, 9)	0.0 (0, 22, 10)
Control (n = 15)	6	0.0 (0, 103, 9)	0.0 (0, 26, 11)	0.0 (0, 9, 12)
	0	146.5 (87, 347, 0)	58.5 (0, 186, 1)	14.0 (0, 124, 1)
	6	46.0 (0, 319, 2)	10.5 (0, 366, 4)	5.5 (0, 204, 3)

tion homes, 3 bedroom floors had allergen levels below the sensitization threshold, and 9 had levels below the asthma morbidity threshold.

In bedroom beds of intervention homes, the mean Bla g 1 concentration declined from 6.1 at baseline to 1.0 at month 6, an 84% reduction. Unlike the other locations, the mean allergen concentration decreased little at month 1 in the intervention beds; however, there was a 52% reduction at month 2. The 6-month allergen reduction in intervention homes was statistically significant ($P =$

.0002) relative to control homes, which had a 47% increase. From baseline to month 6, the number of intervention beds below the sensitization threshold increased from 3 to 13, and the number below the asthma morbidity threshold increased from 9 to 14.

Swab sampling results. For statistical analyses, each sample room was assigned the highest concentration ($U/100\text{ cm}^2$) among the 20 swab samples taken. As with the vacuum sampling, swab sampling indicated that kitchens (all homes combined) had a higher geometric

TABLE III. Geometric mean (95% CI) Bla g 1 concentrations (U/100 cm²) from swab samples by group assignment, month of visit, and sample location*

Group assignment	Month	Sample location		
		Kitchen	Living room	Bedroom
Intervention (n = 16)	0	3.34 (1.71, 6.50)	0.26 (0.12, 0.54)	0.37 (0.14, 0.98)
	1	1.10 (0.48, 2.48)	0.13 (0.06, 0.32)	0.15 (0.06, 0.37)
	2	0.60 (0.30, 1.18)	0.07 (0.03, 0.14)	0.05 (0.02, 0.10)
	4	0.34 (0.10, 1.12)	0.05 (0.02, 0.12)	0.05 (0.02, 0.11)
	6	0.08 (0.04, 0.16)	0.03 (0.02, 0.06)	0.03 (0.01, 0.06)
Control (n = 15)	0	2.93 (1.69, 5.08)	0.33 (0.15, 0.71)	0.19 (0.06, 0.64)
	6	2.02 (0.88, 4.61)	0.20 (0.10, 0.41)	0.42 (0.16, 1.08)

*Each room was assigned the highest of 20 swab sample values.

mean Bla g 1 allergen concentration (3.13; 95% CI, 2.04-4.81) than either living rooms (0.29; 0.17-0.49) or bedrooms (0.27; 0.13-0.58). Table III shows the geometric mean swab sample Bla g 1 concentrations by group assignment, visit, and sample location. From baseline to month 6, reductions in allergen for the kitchens, living rooms, and bedrooms were 98%, 88%, and 92%, respectively, and relative to control homes, each reduction was statistically significant ($P < .001$). Analyses using the mean of the 20 room samples instead of the maximum gave similar results (data not shown).

Correlations between baseline swab sample concentrations and baseline vacuum sample concentrations were assessed among the 31 homes. For a given room, the mean concentration of the 20 swab samples was compared with the concentration of the vacuum sample from the floor. With concentrations log transformed, Pearson correlation coefficients were 0.38 ($P = .04$) for the kitchen, 0.39 ($P = .03$) for the living room, and 0.57 ($P < .001$) for the bedroom.

DISCUSSION

The combined intervention of cockroach insecticide bait placement, resident education, and professional cleaning was efficacious in reducing cockroach infestations and allergen levels in each of the study rooms. Bla g 1 concentrations in vacuumed dust were reduced by 96% on kitchen floors and 83% to 84% at the other sampled sites. The goal of reducing geometric mean Bla g 1 concentrations to below the allergic sensitization threshold of 2 U/g was achieved for the bed, which is likely the most relevant site for exposure.¹⁰ Geometric mean allergen levels were reduced below the asthma morbidity threshold of 8 U/g on living room floors/sofas and bedroom floors. The geometric mean concentration on kitchen floors, which was extremely high at baseline, was reduced 96%, but it remained above the asthma morbidity threshold. The vacuum and swab sample data for the kitchen (Fig 2 and Table III), which show a continual decrease in Bla g 1 concentration over time, suggest that the goal might have been attained if the study period had been extended. Median cockroach trap counts also decreased in control homes, although not as dramatically

as in intervention homes. The decrease among control homes was most likely due to seasonality in cockroach numbers and/or the use of insecticides by householders.

We believe the study homes represented a worst-case scenario. At the screening visit, it was common to see live cockroaches and evidence of a longstanding cockroach infestation. The baseline Bla g 1 level for the intervention kitchens was 9.2 times greater than the baseline level for kitchens in the NCICAS.⁶ Only 2 homes had intact walls, ceilings, floors, and windows. Housing deterioration has previously been associated with increased cockroach infestation and cockroach allergen levels.^{11,12} In our study, the poor condition of the home interiors hampered the thorough removal of allergen and encouraged continued cockroach infestation. Although making home repairs was beyond the scope of this study, we believe it should be considered for any comprehensive allergen abatement program. Finally, homes undoubtedly had large reservoirs of cockroach allergen in clothing and linens and in places that were inaccessible to cleaners, such as inside wall voids and heating and air-conditioning ducts and vents.

Despite the challenges the study homes presented, our intervention was more successful than the intervention used in the NCICAS.⁶ In that 12-month follow-up study, inner-city homes received professional home exterminations, and families were asked to thoroughly clean their homes. In the bedrooms and living rooms, there were no significant reductions in Bla g 1 concentrations at any follow-up visit. In the kitchens, a significant reduction was only seen at 2 months, and by 12 months, the mean level exceeded the baseline level. One of the reasons stated for the lack of success in the NCICAS was the families' poor compliance with cleaning instructions. The authors stated that the families likely had "little control over their environment and resources, and despite their intentions, were unable to sufficiently implement adequate environmental control."⁶ The findings from the NCICAS and our study suggest that professional cleaning, in conjunction with persistent cockroach control efforts, provides a much better result in inner-city homes than relying entirely on families to perform the cleaning.

The benefits of professional cleaning and cockroach extermination were demonstrated in 2 studies of inner-city homes in Baltimore, Maryland.^{7,8} These 2 studies,

conducted by the same group of investigators, used similar protocols of professional cleaning and pest control treatments. Despite large reductions in Bla g 1 concentrations, geometric mean allergen levels in each study remained above the thresholds for asthma morbidity. However, the authors hypothesized that large percentage reductions in cockroach allergen levels might be clinically beneficial regardless of baseline levels, and they reported that they are currently investigating this important question in an experimental trial.^{7,8}

One innovation implemented in this study was the use of swab sampling for the monitoring of Bla g 1 concentrations. The swab technique for the detection of cockroach allergen, which does not require the use of any specialized equipment, provides a major advantage over the vacuum technique—it allows for the detection of allergen in multiple, small locations within a room. The major disadvantage of the swab technique is that it produces Bla g 1 concentrations expressed in U/area, a measure of allergen load.¹⁰ Most relationships between cockroach allergen exposure and allergic disease in humans have been based on vacuum sample concentrations expressed in U/g. Although vacuum sample concentrations can also be expressed in U/area if the area vacuumed is known, 3 of the 4 vacuum samples in this study were based on time instead of area. The sole purpose of swab sampling in this study was to provide spatial Bla g 1 data so that the cleaners could target their cleaning. Future studies will describe the within-room spatial distribution of Bla g 1, will compare allergen concentrations from swab and vacuum sampling, and will examine the relevance of allergen exposures as determined from swab sampling to asthma and allergic disease. Another innovation was the use of room layout maps to guide the interventions and monitor allergen levels through time. Whether the maps contributed significantly to the lowering of allergen levels cannot be determined from this study; however, at the very least, they allowed for more efficient bait placement and cleaning.

We estimate that the cost of reproducing this intervention, including resident education and the use of professional cleaners and pest control operators, would be approximately \$2900 per home. The cost of allergen monitoring, including swab and vacuum sampling, laboratory analyses for Bla g 1, and the preparation of layout maps, would be approximately \$4400 per home. Home repair, which we believe could help lower allergen levels even further, would add significantly to the cost. Because 80% of the monitoring cost is the laboratory cost associated with the multiple swab sampling, significant savings could be realized by decreasing the frequency and/or number of samples. Although the cost of this intervention is relatively high, it could potentially provide a cost benefit if it were successful in the prevention of asthma morbidity. The average cost of a hospital stay for a patient with asthma was \$3102 in 1996 to 1997.¹³

This study demonstrated that large percentage reductions in cockroach allergen levels can be achieved in low-income, urban homes and that levels in the bed can be reduced below levels thought to be associated with the development of allergic sensitization. Evidence from this study and others suggests that cockroach allergen abatement programs in inner-city homes should include professional control of cockroaches, professional cleaning, and perhaps interior home repair. A future study will evaluate whether a cockroach allergen abatement program based on these methods is effective in the primary and secondary prevention of asthma.

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