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ORIGINAL ARTICLE

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Results of a Home-Based Environmental Intervention among Urban Children with Asthma

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ABSTRACT

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*The institutions and investigators that participated in the study are listed in the Appendix.

BACKGROUND

Children with asthma who live in the inner city are exposed to multiple indoor allergens and environmental tobacco smoke in their homes. Reductions in these triggers of asthma have been difficult to achieve and have seldom been associated with decreased morbidity from asthma. The objective of this study was to determine whether an environmental intervention tailored to each child's allergic sensitization and environmental risk factors could improve asthma-related outcomes.

METHODS

We enrolled 937 children with atopic asthma (age, 5 to 11 years) in seven major U.S. cities in a randomized, controlled trial of an environmental intervention that lasted one year (intervention year) and included education and remediation for exposure to both allergens and environmental tobacco smoke. Home environmental exposures were assessed every six months, and asthma-related complications were assessed every two months during the intervention and for one year after the intervention.

RESULTS

For every 2-week period, the intervention group had fewer days with symptoms than did the control group both during the intervention year (3.39 vs. 4.20 days, P<0.001) and the year afterward (2.62 vs. 3.21 days, P<0.001), as well as greater declines in the levels of allergens at home, such as *Dermatophagoides farinae* (Der f1) allergen in the bed (P<0.001) and on the bedroom floor (P=0.004), *D. pteronyssinus* in the bed (P=0.007), and cockroach allergen on the bedroom floor (P<0.001). Reductions in the levels of cockroach allergen and dust-mite allergen (Der f1) on the bedroom floor were significantly correlated with reduced complications of asthma (P<0.001).

CONCLUSIONS

Among inner-city children with atopic asthma, an individualized, home-based, comprehensive environmental intervention decreases exposure to indoor allergens, including cockroach and dust-mite allergens, resulting in reduced asthma-associated morbidity.

I NNER-CITY CHILDREN WITH ASTHMA ARE commonly exposed to multiple indoor allergens and environmental tobacco smoke,[1-6] exposures that may contribute to the increased asthma-related complications in this population.[7-11] Asthma-management guidelines[12] have stressed the need for environmental control measures, but there is limited evidence of their efficacy. Previous studies of environmental interventions for patients with asthma have focused on a single allergen, such as dust mites, or environmental tobacco smoke, rather than on the multiple exposures encountered by many urban children with asthma. Measures to avoid exposure to dust mites, including bedding encasement, have reduced the levels of exposure to these allergens,[13-21] but their clinical effectiveness remains a matter of controversy.[20,22-25] Exposure to cockroach allergens may aggravate asthma among sensitized urban children,[26] but reducing allergen levels in inner-city homes has proven difficult[27-29] and has had no apparent clinical benefit.[20,27] Efforts to use educational approaches to reduce exposure to environmental tobacco smoke in the home have also been disappointing[30-32]; however, the use of interventions including air filtration has not been reported in this population. One potential limitation of all these intervention strategies is their focus on decreasing exposure to a single allergen, rather than improving the indoor environment as a whole.

The Inner-City Asthma Study evaluated the effectiveness of a multifaceted, home-based, environmental intervention for inner-city children with asthma. The objective of the study was to determine whether an intervention tailored to each child's sensitization and environmental risk profile could improve the symptoms of asthma and decrease the use of health care services.

METHODS

We enrolled children 5 through 11 years of age in whom asthma had been diagnosed by a physician at research centers in the Bronx, New York; Boston; Chicago; Dallas; New York City; the Seattle and Tacoma, Washington, area; and Tucson, Arizona. Eligibility was limited to residents of census tracts in which at least 20 percent of households had incomes below the federal poverty level. Other eligibility criteria included at least one asthma-related hospitalization or two unscheduled, asthma-related visits to the clinic or emergency department during the previous six months and a positive skin test in response to at least 1 of 11 indoor allergens. Children were not enrolled within three weeks after an asthma-related hospitalization or visit to the emergency department and could not have any other serious chronic illness. All appropriate institutional review boards approved this study. Written informed consent was obtained from each participant's parent or legal guardian, and children gave assent.

A two-by-two factorial design was used to evaluate environmental and physician-feedback interventions in the same study population. The physician-feedback intervention included bimonthly reports of the children's asthma symptoms and use of health care services to their primary care physicians. There was no interaction between the two interventions, so their effects are considered separately; this article describes the results of the environmental intervention.

A baseline clinical evaluation included questionnaires on complications related to asthma and the home environment. Skin testing was performed with the use of the percutaneous MultiTest method (MultiTest II, Lincoln Diagnostics), involving extracts of German and American cockroach (Bayer) and of the dust mites *Dermatophagoides farinae* and *D. pteronyssinus*, rat, mouse, the fungi *Alternaria alternata*, *Cladosporium herbarum*, aspergillus mix, and *Penicillium chrysogenum*, cat, and dog (all from Greer Laboratories). A response was considered positive if the diameter of the resulting wheal exceeded that caused by the saline control by 2 mm or more.

Approximately three weeks after the baseline clinical examination, a baseline home evaluation was performed that involved both direct visual inspection and dust collection from the child's bedroom. Using a standardized protocol, the home-evaluation team collected separate, vacuumed dust samples from the child's bedroom floor and bed. Dust samples were stored at −20°C and then analyzed in batches for allergens of *D. pteronyssinus* (Der p1) and *D. farinae* (Der f1), cockroach allergen (Bla g1), cat allergen (Fel d1), and dog allergen (Can f1) by means of an enzyme-linked immunosorbent assay.[33,34]

ENVIRONMENTAL INTERVENTION

Children were randomly assigned to either the control group or the intervention group by blocked randomization within a site. Families in the control group received visits only for evaluation at six-

month intervals throughout the study. Neither the study staff nor the children were masked as to group assignment once the intervention had begun.

The goal of the intervention was to provide the child's caretaker with the knowledge, skills, motivation, equipment, and supplies necessary to perform comprehensive environmental remediation. We used an approach that was based on social learning theory.[35,36] This theory emphasizes the importance of a person's attitudes and expectations and modeled behavior in evoking behavioral change. For each component of the intervention, we attempted to educate the family regarding the importance of the mitigation behavior and its effectiveness, while at the same time modeling the targeted behavior. The caretakers were then asked to perform the mitigation behavior while the environmental counselors provided feedback and encouragement. The intervention was organized into six modules that focused on remediation of exposure to dust mites, passive smoking, cockroaches, pets, rodents, and mold.[6] Intervention activities were tailored to each child's skin-test–sensitization profile and environmental exposures on the basis of the caretaker's report and the study staff's observations during the baseline home evaluation.

During the 12-month intervention, two research assistants conducted five mandatory and two optional home visits. All visits were followed by a telephone call to address any barriers to implementing the remediation plan. Overall, a median of 4 modules was delivered per child in the intervention group (range, 0 to 6) during a median of 5 visits (range, 0 to 7). During the first visit, the intervention teams taught the caretaker about the role of allergens and irritants in the child's asthma and introduced the environmental intervention plan, including the creation of an environmentally safe sleeping zone.[6] Allergen-impermeable covers (Allergy Control Products) were placed on the mattress, box spring, and pillows of the child's bed at this visit. Families were given a vacuum cleaner equipped with a high-efficiency particulate air (HEPA) filter and either a power brush (model S434-I, Miele) if the child's bedroom or family room was carpeted or a bare-floor brush (model S312-I, Miele) and instructed in its use. A HEPA air purifier (model 293, Holmes Products) was set up in the child's bedroom if the child was exposed to passive smoking, sensitized and exposed to cat or dog allergens, or sensitized to mold. For children sensitized and exposed to cockroach allergen, professional pest control (Terminix) was provided.

The study received volume discounts in purchasing products and services from Allergy Control, Greer, Holmes, Miele, MultiTest, and Terminix. None of the vendors were involved in the design of the study or the interpretation of the results.

FOLLOW-UP HOME EVALUATIONS

Follow-up surveys of the home environment and collection of dust allergens were repeated at 6, 12, 18, and 24 months according to the same protocol described above in order to assess changes in the home environment. The teams conducting the home-environment evaluations differed from the environmental-intervention teams. However, it is unlikely that the evaluation teams were masked to the study group because of the presence of study materials such as HEPA vacuum cleaners in the homes of the intervention-group families.

OUTCOME MEASURES

Interviewers masked to the children's study-group assignment conducted standardized telephone interviews with each child's primary caretaker every two months during both the year of intervention and the year after the intervention. These interviewers collected data on asthma symptoms, medication use, and health care use. The primary outcome was the maximal number of days with symptoms in the two weeks before the telephone interview, defined as the largest value among the following three variables: number of days with wheezing, tightness in the chest, or cough; number of nights with disturbed sleep as a result of asthma; and number of days on which the child had to slow down or discontinue play activities because of asthma.

Spirometry was performed at baseline and 12 months after randomization with a Renaissance II spirometer (Nellcor Puritan Bennett), according to the guidelines of the American Thoracic Society.[37] The peak expiratory flow rate was measured (in liters per minute) twice daily for a period of two weeks at baseline and every six months thereafter with the use of a digitally recording peak flowmeter (Air-Watch, ENACT Health Management Systems, or Simplicity, Nellcor Puritan Bennett), which was modified to mask the results.

STATISTICAL ANALYSIS

All analyses were performed according to the intention to treat, regardless of the number of intervention visits conducted. Participants were required to have had at least one follow-up assessment for symptoms and health care use related to asthma and

one follow-up assessment of allergens. The difference in asthma-related outcomes between groups was modeled with the use of a linear mixed model with fixed effects for treatment group and visit, with adjustment for baseline symptoms and study site. Differences in the one-year risk of hospitalization were evaluated with the use of a two-sided Cochran–Mantel–Haenszel analysis, stratified according to whether the child had been hospitalized at any time in the two months before baseline. Differences in pulmonary function between the groups were analyzed with the use of analysis of variance, with adjustment for baseline measurement and site. Children had to have data for at least 3 days within a given 14-day period of measurement to be included in analyses of peak expiratory flow rate. Log-transformed allergen levels were modeled with the use of a linear mixed model, and between-group differences in the change from baseline to the average of the post-baseline levels were then calculated. We used a linear mixed model to assess whether reductions in the levels of allergens were associated with decreased asthma-related morbidity. Each allergen was considered separately because the changes in allergen levels were highly collinear, limiting the value of including multiple allergens in a single analysis. All statistical analyses were performed with the use of SAS software (version 8.02, SAS Institute).

RESULTS

STUDY POPULATION

A total of 1059 inner-city children with moderate-to-severe asthma were screened for possible enrollment (Fig. 1) between August 1998 and July 1999. Of these, only 65 (6.1 percent) had no skin-test reactions to any indoor allergens and were thus ineligible for enrollment. Another 57 children (5.4 percent) were excluded because their caretakers did not complete the baseline home evaluation. A total of 937 children with a mean age of 7.7 years (range, 5 to 11) were therefore enrolled. There were no significant differences in baseline demographic characteristics between the intervention group and the control group (Table 1). The sample had a small predominance of boys, and the majority of children were black or of Hispanic descent (race or ethnic background was reported by each child's caretaker). A majority had annual household incomes below $15,000. Over 87 percent of the children completed the two-year study, with 869 having at least one follow-up assessment for asthma-related symptoms and health care use and at least one bedroom-dust
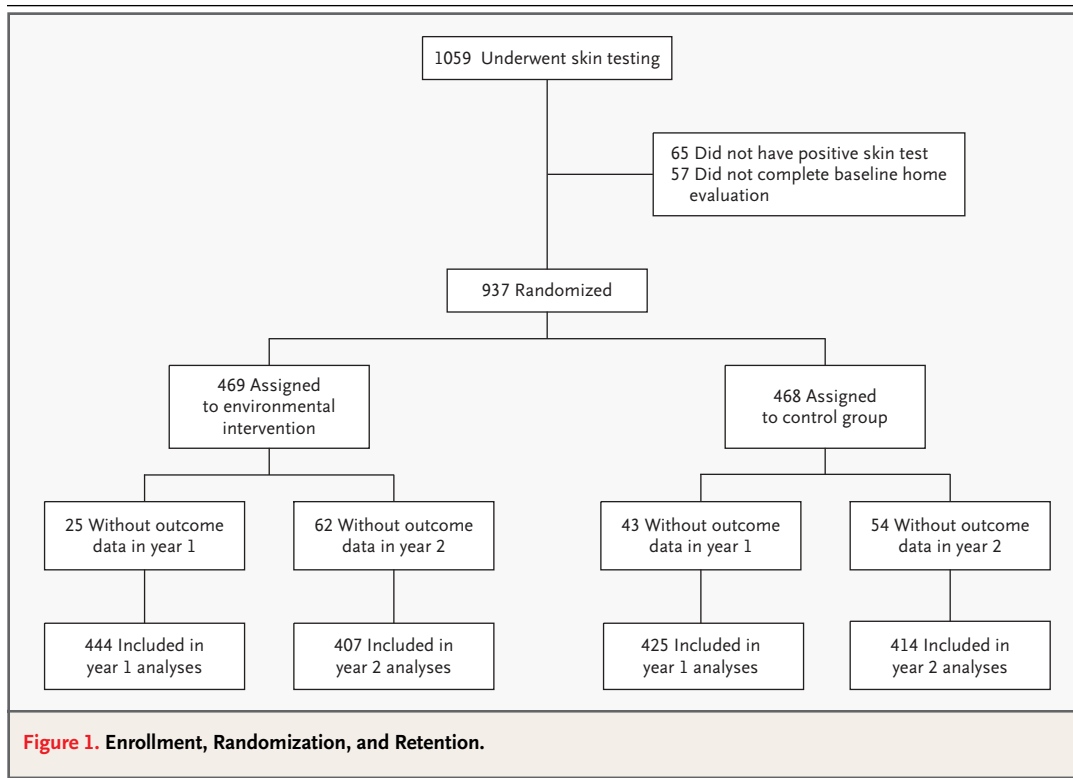

Figure 1. Enrollment, Randomization, and Retention.

Table 1. Baseline Characteristics of the 937 Children.*		
Characteristic	Intervention Group (N=469)	Control Group (N=468)
Demographic		
Age of child (yr)	7.6±0.09	7.7±0.09
No. of other children in the home	1.7±0.06	1.6±0.06
Male sex (%)	63.1	62.2
Race or ethnic group (%)†		
Black	37.7	41.5
Hispanic	40.3	40.0
Other	22.0	18.5
Caretaker completed high school (%)	69.2	69.7
≥1 Household members employed (%)	76.0	75.8
Household income <$15,000 (%)	59.8	60.9
Medications (%)		
Antiinflammatory agents	46.8	45.5
Beta-agonists	84.4	85.9
Asthma-related symptoms within 2 wk before baseline (no. of days)		
Maximal no. of days with symptoms	6.0±0.23	6.0±0.24
Days of wheeze	4.5±0.20	4.2±0.20
Days child had to slow down or stop play because of asthma	3.9±0.22	3.9±0.22
Nights child woke up because of asthma	2.9±0.18	2.6±0.18
Nights caretaker woke up because of child's asthma	3.2±0.20	2.9±0.19
Days caretaker changed plans	1.6±0.14	1.4±0.13
School days missed	1.1±0.10	0.9±0.07
Baseline lung function‡		
FEV$_1$ (% of predicted value)	88.3±0.83	87.3±0.82
Forced vital capacity (% of predicted value)	96.5±0.79	96.9±0.79
Daily variability in PEF (%)§	20.5±0.82	18.2±0.81§
Days with >20% variability in PEF§	37.0±1.98	31.2±1.95§
PEF in a.m. (liters/min)	202.3±4.36	205.4±4.18
Asthma-related health care use in 2 mo before baseline (%)		
≥1 Unscheduled visits to emergency department or clinic	49.4	53.3
≥1 Hospitalizations for asthma	14.4	13.7
Positive skin tests (%)		
Cockroach allergen	67.8	70.3
Dust-mite allergen (Der p1 or Der f1)	62.8	63.3
Mold	51.8	48.1
Cat allergen	40.8	47.8
Rodent allergen (rat or mouse)	33.3	33.6
Dog allergen	21.4	22.6

Table 1. (Continued.)

Characteristic	Intervention Group (N=469)	Control Group (N=468)
Environmental exposures		
Evidence of cockroaches (%)	61.6	61.5
≥1 Current smokers in home (%)	50.1	46.6
Water, dampness, or leaks in home in past 12 mo (%)	45.7	45.2
Dog currently living in home (%)	22.4	22.0
Cat currently living in home (%)	18.6	16.7
Bed allergen levels		
Bla g1 (U/g)		
Median	0.20	0.20
Interquartile range	0.05–1.26	0.05–1.38
Der f1 (μg/g)		
Median	0.10	0.10
Interquartile range	0.015–0.61	0.015–0.66
Der p1 (μg/g)		
Median	0.03	0.03
Interquartile range	0.015–0.86	0.015–0.76
Fel d1 (μg/g)		
Median	0.09	0.09
Interquartile range	0.03–0.85	0.03–0.86
Can f1 (μg/g)		
Median	0.54	0.54
Interquartile range	0.11–2.47	0.11–2.03
Floor allergen levels		
Bla g1 (U/g)		
Median	0.57	0.57
Interquartile range	0.05–5.88	0.05–4.14
Der f1 (μg/g)		
Median	0.03	0.03
Interquartile range	0.015–0.24	0.015–0.25
Der p1 (μg/g)		
Median	0.015	0.015
Interquartile range	0.015–0.35	0.015–0.33
Fel d1 (μg/g)		
Median	0.04	0.04
Interquartile range	0.01–0.32	0.01–0.33
Can f1 (μg/g)		
Median	0.27	0.27
Interquartile range	0.03–1.88	0.03–1.42

* Plus–minus values are means ±SE. Unless otherwise indicated, there were no significant differences between the two groups. PEF denotes peak expiratory flow.
† Race or ethnic group was reported by the child's caretaker.
‡ Test results were available for the following numbers of children: for forced expiratory volume in one second (FEV_1), 372 in the intervention group and 374 in the control group; for forced vital capacity, 367 and 371, respectively; for PEF, 258 and 267, respectively; and for daily variability, 185 and 172, respectively.
§ P=0.03 for the comparison with the intervention group.

sample obtained in the first year, and 821 doing so in the second year.

BASELINE SENSITIVITY TO ALLERGENS AND ENVIRONMENTAL EXPOSURE

There were no significant differences in baseline allergen sensitivity and environmental exposures between the groups (Table 1). The children in both groups had a high prevalence of allergic sensitization to cockroach and dust-mite allergens, and exposure to tobacco smoke and aeroallergens was common. Detectable levels of cockroach allergen (Bla g1) were found in 68.4 percent of bedrooms; 20.8 percent of children had a cockroach-allergen level above 2 U per gram in their beds or on their bedroom floors. Dust-mite allergen (Der p1 or Der f1) was found in 84.1 percent of bedrooms, and 27.6 percent had a dust-mite–allergen level of more than 2 μg per gram in their beds or on their bedroom floors. In addition, 76.8 percent of children sensitive to cockroach and 86.7 percent of those sensitive to dust-mite allergen had detectable levels of these allergens in their bedrooms. Levels of cockroach allergen were higher on the bedroom floor than in the bed (P<0.001), whereas levels of dust-mite, cat, and dog allergen were higher in the bed than on the floor (P<0.001 for all comparisons).

EFFECT OF INTERVENTION ON ASTHMA SYMPTOMS, HEALTH CARE USE, AND LUNG FUNCTION

The intervention group reported significantly fewer symptoms of asthma during both the intervention year and the follow-up year (Table 2). The maximal number of days with symptoms was lower in the intervention group by 0.82 day per 2-week period in the first year (P<0.001) and 0.60 day per 2-week period in the second year (P<0.001). As Figure 2 shows, the greater reduction in asthma-related symptoms in the intervention group occurred within two months after randomization and was sustained for the two years of study. Carpeting in the home did not modify the effect of the intervention on symptoms. There were also significant reductions in the disruption of caretakers' plans, caretakers' and children's lost sleep, and school days missed by the children in the intervention group. The intervention group also reported significantly fewer unscheduled asthma-related visits to the emergency department or clinic during the intervention year than did the control group (P=0.04)

(Table 2); however, this difference decreased during the follow-up year. During the first year, for every 2.85 children treated, there was one fewer unscheduled visit for asthma. There was no significant effect of the environmental intervention on lung function during the intervention year as measured by either spirometry or peak-flow monitoring.

EFFECT OF INTERVENTION ON THE HOME ENVIRONMENT

Levels of cockroach allergen (Bla g1) and dust-mite allergens (Der f1 and Der p1) in the bedroom decreased in both groups over the course of the study; however, greater reductions occurred in the intervention group (Table 3). In the first year, the intervention group had significantly greater declines than the control group in Der f1 (P<0.001) and Der p1 (P=0.007) in the bed and Bla g1 (P<0.001) and Der f1 (P=0.004) on the bedroom floor. During the second year, the reduction in Der f1 in the bed and Bla g1 on the bedroom floor remained significantly greater in the intervention group. Cat allergen (Fel d1) increased in the control group both in the bed and on the bedroom floor but decreased in the intervention group by 27.8 percent in the bed (P<0.001) and 14.1 percent on the floor (P=0.02). By the second year the reductions in Fel d1 were only significantly different in the bed. There was no difference in allergen reduction between homes with carpets and those without carpeting. There were no significant changes within or differences between the groups during the study in the number of homes with current smokers, signs of water damage, cats, dogs, or visual signs of cockroach infestation (data not shown).

REDUCTION IN ALLERGENS AND ASTHMA-RELATED MORBIDITY

Within the intervention group there was a significant relationship between the reduction in the levels of dust aeroallergens and improvements in reported asthma-associated morbidity (Table 4). Similar relationships were seen in the control group between reductions in allergen levels and improvements in asthma-related symptoms (data not shown). Reductions in bedroom-floor levels of cockroach (Bla g1) and dust-mite (Der f1) allergens in the intervention group were associated with decreases in the maximal number of days with symptoms, the number of hospitalizations, and the number of unscheduled visits for asthma in both years of the study. The es-

Table 2. Effect of Intervention on Symptoms of Asthma and Health Care Use.*

Variable	Intervention Group	Control Group	Difference†	P Value
Year 1				
No. of children	444	425		
Day with symptoms of asthma (no./2 wk)				
Maximal no. of days with symptoms	3.39±0.12	4.20±0.12	−0.82	<0.001
Days of wheeze	2.65±0.11	3.43±0.11	−0.78	<0.001
Days child had to slow down or stop play because of asthma	2.34±0.10	2.84±0.10	−0.49	<0.001
Nights child woke up because of asthma	1.55±0.08	2.17±0.08	−0.62	<0.001
Nights caretaker woke up because of child's asthma	1.70±0.09	2.32±0.10	−0.61	<0.001
Days caretaker changed plans	0.91±0.07	1.22±0.07	−0.31	<0.001
School days missed	0.65±0.04	0.82±0.04	−0.17	0.003
Asthma-related health care use				
Unscheduled visits to ED or clinic for asthma (no./yr)	2.22±0.12	2.57±0.13	−0.35	0.04
ED	0.93±0.07	1.08±0.07	−0.14	0.17
Clinic	1.28±0.09	1.49±0.09	−0.21	0.11
≥1 Hospitalizations for asthma (%)	17.1	15.5	1.6	0.56‡
Pulmonary function				
FEV_1 at 12 mo (% of predicted value)	87.0±0.77	87.4±0.78	−0.4	0.69
FVC at 12 mo (% of predicted value)	97.3±0.72	98.1±0.73	−0.8	0.48
Daily variability in PEF in 1st yr (%)	16.6±0.83	15.0±0.81	1.6	0.09
Days with >20% variability in PEF in 1st yr (%)	26.8±2.00	23.3±1.96	3.48	0.14
PEF in a.m. in 1st yr (liters/min)	216.7±3.11	219.3±2.96	−2.61	0.51
Year 2				
No. of children	407	414		
Maximal no. of days with symptoms of asthma (no./2 wk)				
Days with maximal symptoms	2.62±0.12	3.21±0.13	−0.60	<0.001
Days of wheeze	2.28±0.11	2.87±0.11	−0.60	<0.001
Days child had to slow down or stop play because of asthma	1.67±0.10	2.13±0.10	−0.46	0.001
Nights child woke up because of asthma	1.27±0.08	1.57±0.08	−0.30	0.01
Nights caretaker woke up because of child's asthma	1.31±0.09	1.68±0.09	−0.37	0.006
Days caretaker changed plans	0.72±0.06	0.87±0.06	−0.15	0.09
School days missed	0.54±0.04	0.71±0.04	−0.17	0.009
Asthma-related health care use				
Unscheduled visits to ED or clinic for asthma (no./yr)	1.39±0.10	1.66±0.10	−0.26	0.07
ED	0.55±0.06	0.62±0.06	−0.07	0.38
Clinic	0.85±0.08	1.03±0.08	−0.19	0.09
≥1 Hospitalizations for asthma (%)	10.6	13.5	−2.6	0.19‡

* Plus–minus values are means ±SE, adjusted for site and baseline levels. ED denotes emergency department, FEV_1 forced expiratory volume in one second, FVC forced vital capacity, and PEF peak expiratory flow.
† Unrounded values were used to determine the difference between groups.
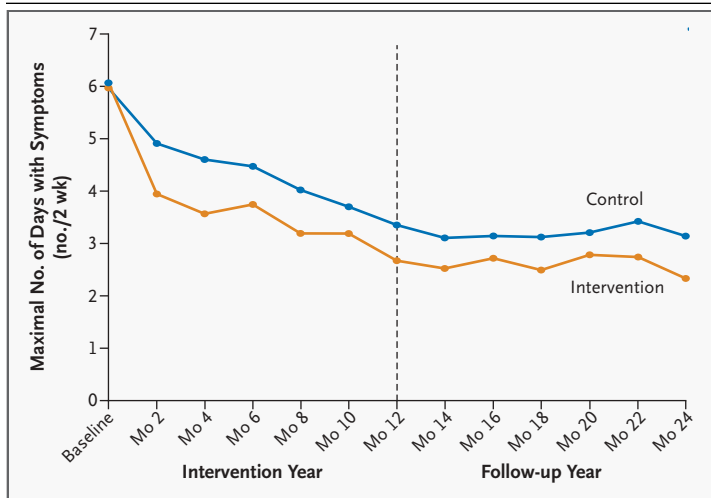‡ The P value was calculated by means of the Cochran–Mantel–Haenszel test.

Figure 2. Mean Maximal Number of Days with Symptoms for Every Two-Week Period before a Follow-up Assessment during the Two Years of the Study.

The difference between the groups was significant in both the intervention year (P<0.001) and the follow-up year (P<0.001).

timated effects of a 50 percent reduction in allergen levels from baseline on these outcomes are presented in Table 4. This level of reduction was found in 52.1 percent of all children with detectable Bla g1 on their bedroom floor and 48.9 percent of all participants with detectable Der f1 in their bed. The correlation between reduction in levels of cockroach allergen on the bedroom floor and reduction in asthma-related morbidity was particularly strong.

DISCUSSION

We found that a home-based intervention focused on reducing exposure to multiple indoor allergens and environmental tobacco smoke decreased reported symptoms among inner-city children with atopic asthma. The observed reduction in symptoms translates into 34 fewer days with reported wheeze during the 2 years of the study among children in the intervention group as compared with those in the control group. This effect is similar to that described in placebo-controlled studies of inhaled corticosteroids.[38] Unscheduled visits for asthma were also reduced slightly during the intervention year. The risk of hospitalization was not significantly changed; however, this study was not powered to detect a reduction in this infrequent outcome. Changes in lung function over the intervention year did not differ significantly between

groups. However, clinical trials of inhaled corticosteroids[38,39] in children and adolescents have demonstrated subtle improvements in lung function before a bronchodilator is given, in contrast to the marked improvements seen in symptoms, exacerbation rates, and health care use.

Although children with asthma are commonly sensitized to multiple indoor allergens, most previous clinical trials of remediation interventions have targeted only one allergen[23,27,40] or have not dealt with environmental tobacco smoke.[20] In contrast, our intervention was multifaceted, mirroring current guidelines for environmental remediation.[12] As suggested in response to the recent failures of approaches involving reductions in exposure to a single allergen, clinically successful allergen avoidance is likely to require "the definition of what patients are allergic to, additional measures beyond the use of mattress covers, and education."[41] One reason that we were able to demonstrate a sustained reduction in allergens may have been that our intervention was based on established models of behavioral change, particularly those based on social cognitive theory.[6,42] Staff members modeled the target remediation behavior, had the caretaker rehearse the behavior, and verified that the caretaker had mastered the behavior. They also reinforced the caretakers' expectations of successful outcomes and their ability to achieve them.[42]

Our findings demonstrate that allergen levels can be successfully reduced in the homes of inner-city children with allergic asthma and that this reduction is associated with a decrease in asthma-related morbidity. The reduction in cockroach allergen is especially notable since it plays such an important role in asthma-related morbidity among children who reside in the inner city.[26] Previous efforts to decrease the levels of cockroach allergen in this setting have not been particularly successful.[27-29] The Institute of Medicine[43] concluded that insufficient evidence was available to determine whether reducing the levels of cockroach allergen in home environments reduces asthma-related morbidity in persons allergic to cockroaches. We found not only a reduction in the levels of cockroach allergen in the bedroom, but also a significant correlation between a reduction in cockroach allergen and a decrease in asthma-related morbidity. Reductions in the levels of dust-mite allergens in the children's bedrooms were also correlated with reductions in the symptoms of asthma and health care use.

Inspection and interview data obtained during

the home evaluations did not reveal significant differences in the observable home environment between the groups over the course of the study. Nonetheless, the greater reductions in the levels of cockroach and dust-mite allergen in the bedroom in the intervention group than in the control group indicate an improvement in the bedroom environment resulting from the intervention's focus on the child's sleeping area, including the use of mattress and pillow covers and a HEPA vacuum cleaner. Owing to the lack of data on allergen levels in other rooms, the relative effects of cockroach extermination and bedroom cleaning cannot be determined. Furthermore, most homes received a HEPA air filter, and a recent meta-analysis[44] has suggested that air filtration is associated with an improvement in asthma-related symptoms. No direct measures of the child's exposure to environmental tobacco smoke were made, so the effect of changes in allergen exposure cannot be separated from the potential benefits of reduced levels of exposure to environmental tobacco smoke.

One limitation of our study is that there were no sham intervention visits for the control group, and thus, although both groups received the same number of telephone interviews, intervention homes were visited more frequently. This frequency of contact could have contributed to the reduction in asthma-related symptoms by increasing caretakers' attention to asthma care[20] or by decreasing their willingness to report symptoms. However, the intervention teams were not clinically trained and were prohibited from discussing the medical management of asthma with the families. Furthermore, reductions in key allergen levels in the bedroom were significantly correlated with the improvement in symptoms in the intervention group. This dose–response relationship suggests that environmental change was central to the improvement in the asthma-related outcomes.

We estimate the cost of the intervention to be in the range of $1,500 to $2,000 per child, or approximately $750 to $1,000 for each year of the study. These costs include personnel and equipment. This is similar to the Drug Topics Red Book[45] cost of mid-range inhaled corticosteroid and albuterol for a child with moderately severe asthma. The benefit of the intervention was apparent during both the treatment year and the year thereafter. If the duration of benefit is assumed to be even longer, the cost per year of benefit would be even lower. The intervention resulted in 2.1 (13.6 percent) fewer un-

scheduled visits per year, 21.3 (19.5 percent) fewer days with symptoms per year, and 4.4 (20.7 percent) fewer missed school days per year. Although the direct health care savings from the intervention may not offset its cost, the overall improvements in terms of societal benefits and the quality of life of children with asthma and their families need to be considered in evaluating the intervention.

Atopic children with asthma who live in the inner city have numerous adverse indoor environmental exposures. We have shown that remediation

Table 3. Effect of Intervention on Allergen Levels.

Allergen	Intervention Group	Control Group	P Value
Year 1			
No. of children	444	425	
	% change from baseline (95% CI)*		
Bed allergens			
Bla g1	−44 (−52 to −35)	−34 (−44 to −24)	0.13
Der f1	−59 (−65 to −51)	−14 (−27 to 0.73)	<0.001
Der p1	−37 (−44 to −28)	−18 (−28 to −6.5)	0.007
Fel d1	−28 (−38 to −15)	15 (−2.5 to 35)	<0.001
Can f1	10 (−5.8 to 29)	24 (6.0 to 46)	0.29
Floor allergens			
Bla g1	−53 (−61 to −43)	−19 (−33 to −2.3)	<0.001
Der f1	−34 (−43 to −23)	−9.8 (−22 to 4.5)	0.004
Der p1	−21 (−30 to −11)	−13 (−23 to −1.6)	0.28
Fel d1	−14 (−28 to 2.0)	15 (−3.2 to 38)	0.02
Can f1	9.9 (−7.9 to 31)	18 (−1.0 to 42)	0.56
Year 2			
No. of children	407	414	
	% change from baseline (95% CI)*		
Bed allergens			
Bla g1	−51 (−57 to −43)	−46 (−53 to −37)	0.39
Der f1	−49 (−58 to −39)	−25 (−38 to −9.8)	0.004
Der p1	−37 (−46 to −27)	−25 (−35 to −12)	0.11
Fel d1	−14 (−28 to 1.7)	30 (8.9 to 54)	<0.001
Can f1	65 (37 to 98)	90 (58 to 129)	0.28
Floor allergens			
Bla g1	−64 (−71 to −57)	−47 (−56 to −36)	0.003
Der f1	−18 (−30 to −3.2)	−13 (−27 to 2.2)	0.66
Der p1	−34 (−43 to −23)	−24 (−35 to −13)	0.20
Fel d1	−13 (−28 to 5.1)	11 (−8.2 to 34)	0.08
Can f1	58 (28 to 94)	82 (48 to 125)	0.33

* CI denotes confidence interval.

Table 4. Relationship between Reductions in Allergens and Changes in Asthma-Related Morbidity among Children in the Intervention Group.*

Variable	Year 1 (N=444)		Year 2 (N=407)	
	Change†	P Value	Change†	P Value
Maximal no. of days with symptoms per 2-wk period				
Bla g1, floor	−0.25±0.063	<0.001	−0.41±0.066	<0.001
Der f1, floor	−0.29±0.071	<0.001	−0.15±0.066	0.02
Der f1, bed	−0.23±0.080	0.004	0.15±0.076	0.04
Der p1, bed	−0.21±0.098	0.03	−0.18±0.089	0.04
Fel d1, bed	−0.085±0.070	0.22	−0.093±0.074	0.21
Fel d1, floor	0.011±0.069	0.87	−0.012±0.067	0.85
No. of unscheduled ED or clinic visits for asthma per 2-mo period				
Bla g1, floor	−0.051±0.014	<0.001	−0.093±0.014	<0.001
Der f1, floor	−0.059±0.016	<0.001	−0.044±0.015	0.003
Der f1, bed	−0.050±0.018	0.006	−0.017±0.017	0.30
Der p1, bed	−0.019±0.022	0.38	−0.024±0.019	0.22
Fel d1, bed	−0.016±0.016	0.32	−0.010±0.017	0.56
Fel d1, floor	−0.016±0.015	0.30	−0.019±0.015	0.18
No. of hospitalizations for asthma per 2-mo period				
Bla g1, floor	−0.018±0.005	<0.001	−0.017±0.005	<0.001
Der f1, floor	−0.015±0.006	0.004	−0.0090±0.0049	0.05
Der f1, bed	−0.0069±0.0062	0.27	−0.0025±0.0055	0.66
Der p1, bed	0.0038±0.0074	0.61	−0.010±0.006	0.13
Fel d1, bed	−0.0069±0.0055	0.20	−0.012±0.006	0.02
Fel d1, floor	−0.0059±0.0052	0.25	−0.0076±0.0049	0.12

* Plus–minus values are estimated means ±SE. The model for year 1 was based on 869 children and the model for year 2 was based on 821 children, but effects are reported only for children in the intervention group.
† The values are the estimated changes in asthma-related morbidity that are associated with a 50 percent reduction in the allergen level from baseline.

strategies can be implemented that result in both sustained reductions in indoor allergen levels and sustained improvements in reported asthma-associated morbidity in this high-risk population. Although it is difficult to generalize our results to all children with asthma, it seems likely that children who are exposed to environmental allergens and irritants similar to those present in the homes of our inner-city study participants may derive a similar benefit from this intervention.

APPENDIX

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