

Low-cost interventions improve indoor air quality and children's health

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ABSTRACT

Intervention in the home environment to reduce asthma triggers theoretically improves health outcomes for asthmatic children. Practical benefit from application of these interventions has proven difficult. This single-blind study tested the effectiveness of simple low-cost home interventions in improving health scores of children with asthma. Families with at least one asthmatic child were recruited. Initial health examination, health, and home assessments were conducted and targeted interventions were implemented. Interventions included dehumidification, air filtration, furnace servicing, and high-efficiency furnace filters. When present, gross fungal contamination was remediated. Asthma education was provided along with education in healthy home practices. Follow-up assessments were conducted after 6 months. Health surveys were completed at enrollment and follow-up. This study enrolled 219 children with asthma. Home inspections and interventions were conducted in 181 homes and 83 families completed all phases. Reduction in asthma and allergy-related health scores was shown in follow-up health surveys. Health improvements were significant for cough when heating, ventilation, and air conditioning (HVAC) service and dehumidification were used. Breathing problems were significantly improved for dehumidification, HVAC service, and room air cleaners. Total dust allergen load was reduced for the dehumidification group ($p < 0.05$). Mold spore counts were reduced one order of magnitude in 25% of the homes. Indoor spore counts adjusted for outdoor spore levels were reduced overall ($p < 0.01$). Simple low-cost interventions directed to producing cleaner indoor air coupled with healthy home education improve the indoor air quality and health in asthmatic children.

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Key words: Aerobiology, air-conditioning, air pollution, allergy, asthma, dust allergens, healthy homes, indoor mold, pediatric, quality of life

Childhood asthma is a chronic illness. Over recent decades it is the most common chronic childhood disease in the United States. The estimated number of U.S. children diagnosed with asthma was 9 million in 2001 with 14.7 million missed school days.¹ Asthma is epidemic in poor urban centers,² and, health care for children with asthma consumes >\$2.0 billion annually.^{3,4}

The role of environmental triggers in childhood asthma exacerbation has been studied often using the hypothesis that providing home interventions can improve indoor air quality (IAQ).⁵ Association between indoor allergen exposure and asthma exacerbation has been frequently documented.^{6–8} Also, effective strategies to reduce indoor allergen load for asthmatic children have been determined.² Recent studies documented the effectiveness of remediation for home asthma triggers for providing asthma control in children.^{5,9} Additional studies have shown low-cost interventions aimed at reducing triggers such as pest management, smoking cessation, and mold remediation to be effective disease management tools.^{10,11} Efforts to determine workable and beneficial childhood asthma control mechanisms have examined the effectiveness of mattress covers,^{12,13} pest management,¹⁴ and smoking cessation.¹⁵ These interventions did reduce allergen exposures but were not always sustainable. In this pilot study we hypothesized that focusing interventions on the most common indoor allergens would decrease home exposure for asthmatic children and thus decrease asthma and allergy symptoms over time. To assess this hypothesis, we conducted a study of asth-

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All human subject use in this study was approved in advance by the Pediatric Internal Review Board of Children's Mercy Hospital; informed consent was obtained from all participants before their participation in the study. No animals were used in this research

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matic children between the ages of 2 and 17 years by assessing their health and home environment before placing targeted interventions in the home and then again after a 6-month follow-up period.

MATERIALS AND METHODS

Organization

This study was conducted in collaboration with the Healthy Homes Network (HHN), a nonprofit organization based in Kansas City (KC), MO, consisting of multiple KC community organizations. HHN is a community-based organization dedicated to the promotion of safe and healthy homes. Over 100 individuals, representing more than 50 nonprofit organizations, public agencies, universities, hospitals, and neighborhood groups, collaborated through HHN to help residents of Metropolitan KC access information and services to improve the quality of their lives. Financial support was provided by the Department of Housing and Urban Development (HUD) as a Healthy Homes Initiative demonstration grant awarded to HHN. Children's Mercy Hospital (CMH) served as subgrantee providing home and health assessments and analytical services.

Recruiting and Enrollment

Children with asthma whose families might be enrolled were identified from the CMH Emergency Room, CMH Allergy Clinic, other CMH primary care clinics, community physicians, and organizations affiliated with the HHN including health departments and housing authorities. As part of enrollment the following criteria were met: the family must either own the home or be able to show a consistent rental history and obtain landlord cooperation; the family must have stayed in the same home for the last 6 months, and expected to stay for the next 12 months. In addition, enrolled homes met requirements specific to HUD. HUD exclusion requirements included presence in a flood plain, presence in a historical area, and association with public housing. If initial screening indicated the family would benefit from participation in the program they were enrolled and a health evaluation visit was scheduled. If results indicated the family would not benefit but they had home health-related issues that required assistance they were referred through HHN to obtain necessary resources. Generally, homes were enrolled if they contained an asthmatic individual between the ages of 2 and 17 years, who resided in the home a minimum of 4 nights/week.

Health Screening and Questionnaires

After enrollment and informed consent was obtained, a baseline health assessment was conducted, and medical history questionnaires were completed.

Based on initial information, any child who was not receiving appropriate medical attention and management was referred for the appropriate services. Initial screening for the program used four questionnaires: enrollment survey, asthma quality of life (AQL) questionnaire, medical history survey, and home health symptom questionnaire. Data collected at enrollment included demographics, breathing problems, nasal congestion, dry sore throat, skin rashes, and other general health symptoms. Also, asthma-specific information was collected including past hospitalizations and frequency of symptoms as wheezing, shortness of breath, cough, and chest tightness. Questionnaires contained a combination of yes/no questions about specific health-related events (*e.g.*, recent hospitalizations) or questions on a 0–5 Likert scale concerning the frequency of symptoms (*e.g.*, morning coughing). These questionnaires have been published previously.¹⁶ AQL questionnaires^{17,18} were also completed by all participants. The AQL, medical history survey, and the home health symptom questionnaire were all completed at the beginning of the study and again 6 months after interventions were placed as part of the follow-up assessment. Questionnaires were completed by the asthmatic child; or, when the child was too young, questions were posed to the child and caregiver by the person conducting the evaluation. For very young children, questionnaires were completed by caregivers.

Materials

Dust collection protocols and immunoassay analysis protocols have been described previously.¹¹ Dust collection sample bags x-cell-100 were purchased from Midwest Filtration (Cincinnati, OH). Air monitors to measure carbon dioxide, temperature, and relative humidity were obtained from TSI, Inc. (St. Paul, MN). Carbon monoxide was measured with an AIM Gas Detector meter (Aim Safety Co., Ottawa, Canada). Rapid test for Mite Allergen detection and MITEST Dust Collectors were obtained from Indoor Biotechnology (Charlottesville, VA). Antibodies for immunoassay measurements were obtained from Greer Laboratories (Lenoir, NC).

Sampling/Experimental Protocol

The home environment was assessed using a specific set of sampling and analyses.¹⁹ On completion of both the health and the home assessment a report was prepared and remediation specifications based on predetermined protocols were developed. For example if high mold spore counts were present, moisture control remediation was indicated; if mold growth was identified, removal and replacement of contaminated surfaces was indicated; if heating, ventilation, and air conditioning (HVAC) problems such as dirty or con-

taminated air exchange unit or improperly fitted filtration were identified, HVAC servicing and improved filtration was indicated. These remediation protocols provided for consistent specifications based on the results of the environmental assessment. Priority for remediation was given to activities that directly reduce environmental contaminants, provided that no imminent hazard existed. Every effort was made to correct any hazard that could result in severe injury or severe acute health effects.

Educational materials were provided during each contact. Information content was expanded in detail and length with each step. For example, potential study subjects were provided generic information about healthy homes at the initial screening.²⁰ Additional educational materials describing specific contaminants and associated health effects were distributed at the initial health assessment. Information about identifying hazards was distributed at the environmental assessment.²¹ Once the initial assessment and report were complete, detailed information on hazard control activities and exposure reduction was provided with the results of the environmental sampling. The health and home assessments were used for in-home education related to specific strategies for creating and maintaining a safe and healthy home. The family received interventions within 60 days of the in-home education.

Environmental Assessment

After the clinic visit a home visit was scheduled and comprehensive assessment of the home environment was conducted. Home assessment was conducted using a procedure for evaluation of the indoor environment developed by CMH.¹⁹ Briefly, the home assessment consisted of a comprehensive set of field and analytical samples for indoor allergens. Volumetric air samples for nonviable mold spores were collected using Allergenco (Allergenco/Blewstone Press, San Antonio, TX.) air samplers with samples collected in the following rooms: child's bedroom, living room, bathroom, kitchen, and basement. Volumetric collections for visual nonviable fungal spores were counted microscopically and reported as estimates of spores per cubic meter of air for 25 taxa commonly identified in airborne samples. For analysis the mean pre- and postintervention spore count for all rooms were compared assuming a log normal distribution common for fungal spores. To take outdoor airborne spore levels into account, one-tenth of the outdoor count was subtracted from the mean indoor count. Comfort indices including temperature and humidity (Rh) were collected concurrently with the air samples. One vacuum dust sample collection was taken in the child's bedroom after a protocol designed for use by HUD's

Healthy Homes Initiative Grantees. In addition, a house composite sample was collected from the home vacuum and both dust samples were sieved in the laboratory using a No. 50 brass sieve. House-dust collections were analyzed by enzyme immunoassay for total antigen content of nine common allergenic species including cats, dogs, dust mites, roaches, mice, *Alternaria*, *Aspergillus*, *Cladosporium*, and *Penicillium*.^{22,23}

Statistical Procedures

Questionnaires involving subject or caretaker recall symptom frequency and severity as well as quality of life (QOL) data were compiled into MS Excel spreadsheets and analyzed using SPSS (SPSS, Inc. Chicago, IL) data software. Homes receiving specific interventions were stratified according to intervention received. Continuous variables were compared for difference between pre- and postintervention groups using the *t*-tests function of SPSS.

RESULTS

Between December 2003 and January 2005, 500 families were screened for this study and 219 were enrolled and approved to participate. Of the 219 families, 186 completed the initial clinic visit and the first home assessment. Interventions were completed on these 186 homes. The major reason for dropping out was non-compliance including failure to keep appointments and loss of interest due to long waiting times. Of the 186 participants with completed interventions there were 83 follow-up home assessments ~6 months after the completion of interventions. The major reason for participants not completing the follow-up visit included participants not keeping appointments, participants becoming unreachable, participants leaving the residence, and participants with disconnected phones.

From the 186 homes, 219 subject children were included in the study. The mean age for children enrolled was 9 years. Boys accounted for 59% (129) and girls accounted for 41% (90). Ethnicity was split as follows: 56% black (123), 33% white (72), and 11% other (24). The majority of the homes (75%) included in this project were located in the urban core of KCMO. The mean age of the homes was ~65 years. Nearly all (98%) of the homes had a basement and all had some form of air conditioning. Income data were not collected; however, according to the most recent KC census data (2000), 43% of households in the urban core have incomes below \$10,000. The mean spirometry on enrollment for the asthmatic subjects who completed the study was 80% of the predicted value. On enrollment subjects completing the study had complaints of coughing (85%), wheezing (67%), or shortness of breath (56%). Skin test or specific IgE testing indicated

Table 1 Most frequently used standardized interventions

Intervention	Frequency (%)
Service furnace	78.2
Install basement ground fault interrupt	77.2
High-efficiency furnace filters	72.3
Room air cleaner	69.3
Install kitchen ground fault interrupt	66.3
Carbon monoxide detector	65.3
Install basement dehumidifier	54.5
Install bathroom ground fault interrupt	51.5
Smoke detector	35.6
Dryer exhaust ventilation	35.6

that 46% of the subjects completing the study were demonstrated atopics.

The top 10 standardized interventions and the frequency of their application in all homes enrolled in the study are listed in Table 1. Of the 83 participants completing the study 58 received complete professional HVAC service, which included the installation of a pleated Allergy Zone furnace filter (minimum efficiency reporting value, 12), 56 received a room air cleaner (clean air delivery rate, ≥ 150) placed in the primary child's bedroom, 46 received a dehumidifier placed in the basement of the home, and 28 received all three of the aforementioned interventions. In addition, homes were cleared of visible mold and sources of water intrusion into the structure were repaired.

IAQ data displayed in Table 2 include both temperature and humidity with significance reported for relative humidity only. A decrease in humidity was observed in all five of the rooms where readings were collected with the bathroom having the most significant reduction postintervention.

Asthma and Allergy Symptoms

The comparison of asthma-specific symptoms before and after intervention is seen in Fig. 1. Questions including frequency of cough, wheezing, and shortness of breath were compared for major intervention types (HVAC service, dehumidification and room air cleaner). Statistical analysis indicates coughing was significantly reduced ($p < 0.005$) for homes receiving one of the three interventions and for homes receiving all three of the interventions. Wheezing was slightly but not significantly decreased overall and increased or stayed the same when dehumidification and room air cleaners were evaluated alone. Reports of shortness of breath were not improved by any of the major interventions and were not significantly different overall.

General health symptoms evaluated using yes/no questions including breathing problems, allergy attacks and asthma attacks are listed in Table 3. Subjects reported breathing problems decreased significantly with all four intervention types. The most effective intervention types at reducing breathing problems were HVAC servicing ($p < 0.05$) and dehumidifiers ($p < 0.05$). However, sore throat frequency and skin rashes were not significantly impacted with these interventions (Table 3). One of the most highly significant findings was the decrease in allergy attacks with all intervention types.

AQL surveys (Table 4) collected during phase I and phase II of the study showed an improvement in QOL after intervention. The questions asked on the AQL surveys were scored on a scale of 1–7 with 1 representing *all of the time* and 7 representing *none of the time*; thus, an increase in score in the postintervention AQL survey indicates a perceived improvement in the child's QOL. The mean scores presented in Table 4 show improvements in many areas.

Environmental Measures

Dust Samples. Total allergen load in the child's bedroom composite and for the home vacuum samples was compared pre- and postintervention. There was numeric reduction in total dust borne allergens in 61% of homes tested although there was no significant change in total dust allergen level either in the child's bedroom or in the house composite sample. This was the case when data were analyzed for the three individual interventions and also for homes that received all three main remediations. The stratum where significant reduction was nearly achieved was in the dehumidification group. The total before and after dust samples from homes receiving dehumidifiers was 31 and the mean total allergen load from the home composite sample was reduced from 2.50 U/g to 2.03 U/g ($p = 0.059$).

Nonviable Mold Spores. The median nonviable mold spore count decreased with all three intervention groups postintervention. The geometric adjusted mean for all interventions in the preremediation homes was 486 spores/ m^3 of air and for the postremediation was 96 spores/ m^3 of air. When log normal distribution was assumed for spore counts, postremediation airborne spore levels adjusted for outdoor spores was significantly lower ($p < 0.01$) than preremediation levels similarly adjusted. When homes were examined individually we found a decrease of 10-fold or more in 25% of the homes and a simple decrease in spore counts in 66% of homes.

Table 2 Means and standard deviations for indoor air quality results for pre- and postintervention assessments for all rooms sampled in the homes receiving interventions

Location	Temperature Preintervention	Temperature Postintervention	Rh Preintervention	Rh Postintervention	Significance
Child's bedroom (n = 58)	73 (± 4.47)	74 (± 5.66)	45.75 (± 13.13)	41.09 (± 13.56)	NS
Bathroom (n = 56)	73 (± 4.49)	74 (± 5.50)	47.17 (± 13.69)	40.92 (± 13.66)	<0.05
Living room (n = 60)	73 (± 4.55)	74 (± 5.86)	44.79 (± 13.60)	40.52 (± 13.41)	NS
Kitchen (n = 62)	73 (± 4.81)	74 (± 5.64)	44.24 (± 13.72)	40.12 (± 13.60)	NS
Basement (n = 59)	70 (± 5.72)	69 (± 5.85)	45.15 (± 15.17)	44.20 (± 15.71)	NS

Significance values represent Rh only.

Rh = relative humidity.

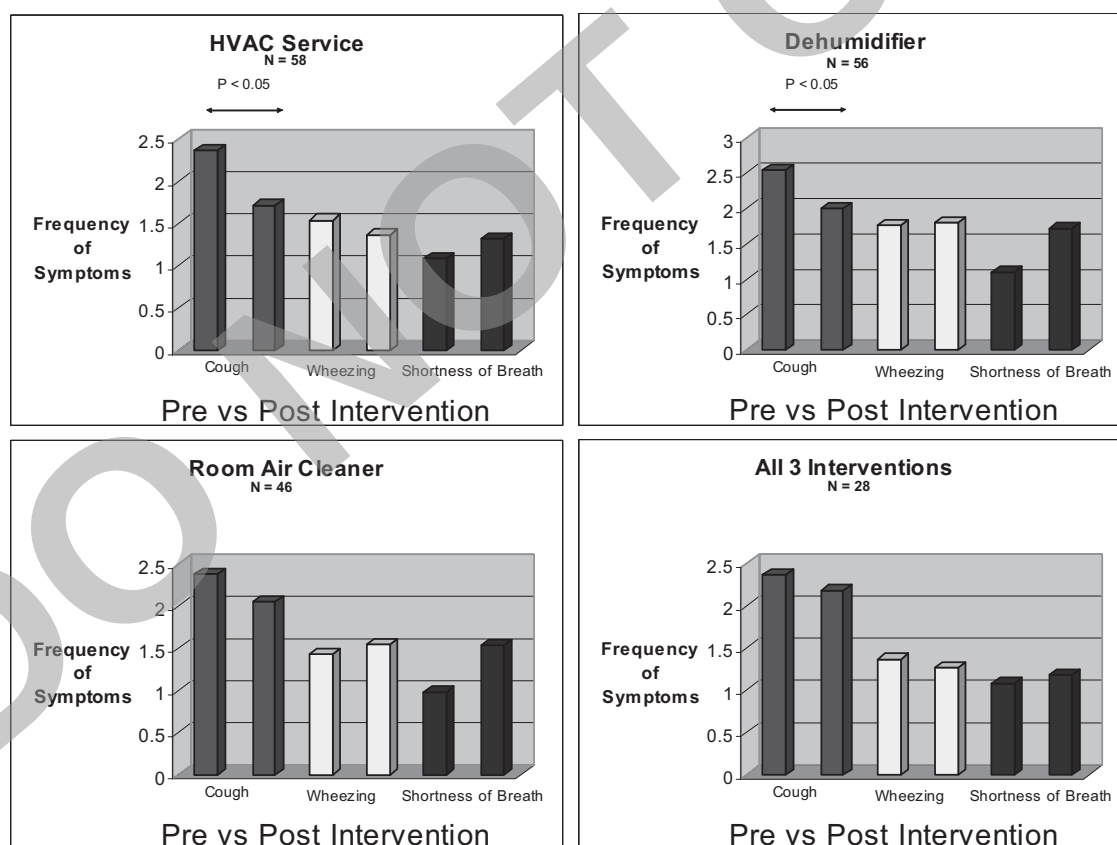


Figure 1. Representation of the reported asthma-related symptoms including cough, wheeze, and shortness of breath for children in the study before and 6 months after implementation of three common home interventions. Symptoms are before and after intervention only for homes that received the specific intervention listed. Results represent 58 individuals who received heating, ventilation, and air conditioning (HVAC) service; 56 individuals who received HVAC basement dehumidifiers; 46 individuals who received room air cleaners alone; and 28 individuals who received all three interventions. Symptom questions were rated from 5 (all of the time) to 1 (none of the time), so lower numbers represent improving asthma.

DISCUSSION

This study was conducted to test the hypothesis that targeted low-cost interventions in homes of children

with asthma lessen asthma symptoms and improve AQL. The majority of homes in the study were from urban areas reflected in their average age and condi-

Table 3 Means from Healthy Home Survey for general respiratory symptoms

Intervention	HVAC Service <i>n</i> = 14			Dehumidifier <i>n</i> = 11			Room Air Cleaner <i>n</i> = 16			All Interventions <i>n</i> = 11		
	Pre-intervention	Post-intervention	Significance	Pre-intervention	Post-intervention	Significance	Pre-intervention	Post-intervention	Significance	Pre-intervention	Post-intervention	Significance
In the past 2 wk have you had												
Breathing problems	69	43	<0.05	90	50	<0.05	81	44	<0.05	90	55	<0.05
Nasal congestion	92	64	NS	90	60	NS	94	62	<0.05	91	63	NS
Dry sore throat	35	42	NS	50	50	NS	37	43	NS	40	35	NS
Skin rashes	50	28	NS	60	30	NS	50	31	NS	45	27	NS
Allergy attacks	86	35	<0.01	80	30	<0.05	87	37	<0.005	81	36	<0.01
Asthma attacks	57	38	NS	60	30	NS	56	31	NS	63	36	NS

Responses to general health questions before and after remediation. Numbers represent percent yes answers.

tion problems. Interventions and frequency of application are listed in Table 1. Major interventions impacting air quality were HVAC maintenance, dehumidification, and improved air filtration. Additional basic work to address safety concerns including electrical safety device installation was performed but these were not included in this analysis. Targeted interventions for this data set were chosen to address IAQ issues associated with asthma exacerbation. Room air cleaners and furnace servicing including high-efficiency filters were targeted at cleaning allergens and spores from the indoor air.²⁴ Dehumidifiers were targeted at moisture reduction²⁵ and mold control^{26,27} and HVAC²⁸ servicing was targeted at improving IAQ. Temperature data (Table 2) shows consistency in pre- and postconditions and confirms the use of heating and cooling systems. The Rh data in Table 2 relates to moisture control in the home. A decrease in humidity, sometimes statistically significant, was sustained in the majority of the homes completing this project (Table 2). Living or working in a damp environment has been associated with increased upper and lower respiratory symptoms.^{26,29} Installation of a dehumidifier was a remediation used in at least half of the homes. This could account for much of the symptom improvement. Moisture control is important to control mold growth and to establish lower relative humidity indoors is beneficial in improving air quality for children with asthma.^{26,27,30,31}

All families received asthma trigger and motivational education in home cleaning practices.²¹ Families were encouraged to reduce indoor visible fungi in a responsible manner; and, in the most contaminated circumstances removal of fungal contaminated material was provided. The results of the health surveys (Tables 3 and 4) support our hypothesis that decreased asthma and allergy symptoms can be accomplished through simple low-cost interventions to the home environment. Although there are many uncontrolled confounding variables in studies of this type, when we consider the health data and the environmental data together, the interventions were a success for the majority of children in this study.

Measures to reduce airborne particles (HVAC servicing and improved air filtration) decreased the median postintervention mold spore counts for all groups. When houses were evaluated individually there was a total reduction in nonviable mold spores and a 10-fold decrease in one-quarter of postintervention homes. When adjusted for outdoor spore levels this provided significant postintervention reduction. It has been shown previously that reduction of indoor airborne spore levels can be achieved through proper remediation.³²

Although targeted interventions reduced humidity and removed particles from the air, they were unable to significantly impact overall home dust allergen lev-

Table 4 Mean quality-of-life scores for participants receiving three interventions

AQL Questions	Preintervention <i>n</i> = 14	SD	Postintervention <i>n</i> = 14	SD	Confidence Interval
1. Did you feel helpless or frightened?	4.79	±1.968	4.86	±2.381	−0.94 to 0.80
2. Did your family change plans?	4.47	±2.167	4.73	±2.344	−0.86 to 0.93
3. Did you feel frustrated, impatient, or irritable?	4.60	±2.261	4.73	±2.344	−1.40 to 0.78
4. Did your asthma interfere with your school or work around the house?	4.40	±2.063	5.00	±2.299	−1.47 to 0.26
5. Did you feel upset because of your cough, wheeze, or breathlessness?	4.29	±2.12	4.43	±2.38	−1.04 to 0.75
6. Did you have sleepless nights?	4.21	±2.120	4.29	±2.344	−1.07 to 0.77
7. Were you bothered because asthma interfered with relationships?	5.21	±2.045	5.29	±2.400	−0.97 to 0.81
8. Were you awakened during the night?	4.14	±2.336	4.21	±2.251	−0.98 to 0.84
9. Did you feel angry that you have asthma?	5.29	±2.463	5.14	±2.568	−0.84 to 1.15
During the past week, how worried or concerned were you?					
10. About your ability to perform normal daily activities?	4.43	±2.503	5.29	±2.164	−1.79 to 0.07
11. About your asthma medication and side effects?	4.43	±2.533	5.14	±2.214	−1.65 to 0.23
12. About your parent being overprotective?	5.00	±2.219	5.29	±2.301	−1.18 to 0.60
13. About your being able to lead a normal life?	4.79	±2.424	5.14	±2.413	−1.30 to 0.60

Possible answers are all of the time (1) to none of the time (7). Higher numbers indicate improving asthma.

AQL = asthma quality of life.

els. Total allergen load was reduced in a majority of the homes (61%); however, there was no statistically significant movement in allergen levels. Even though dust samples did not show significant improvement postintervention, when the houses were looked at individually there was a decrease in total allergen load for the majority of homes. The analysis was skewed by high allergen levels in a few homes resulting in large deviations from the mean. Statistical significance was therefore impossible to achieve and these results may not show an accurate picture of the allergen load reduction in many homes. The great disparity in allergen levels measured was probably because of the large allergen reservoir present in carpets and furniture of

many homes.^{33,34} Other studies have not been able to establish significant allergen removal for a variety of reasons.^{13,33–35} Although we provided asthma trigger education and motivation to improve cleaning practices, we were unable to impact the overall allergen reservoir over the 6 months between collection of the pre- and postintervention samples. This was disappointing; however, it points to our poor understanding of the kinetics of allergen introduction and removal from homes.

Other studies have found associations between targeted interventions and improved health scores³⁵ but with limited sustainability. In this study we attempted to show that simple, low-cost interventions could have

a longer reaching impact than previously shown by collecting samples 6 months after placing interventions in the homes. Several issues were raised from the beginning that should be addressed in future work. First, the ability to retain participants throughout both phases of this study proved difficult. Because this was an inner city population, a substantial number of families relocated or were lost to follow-up as a result of disconnected telephones. Future studies should include more frequent communication with participants and possibly additional incentives for the follow-up phase of the study.

Many studies have begun to lay the groundwork for identifying simple solutions to effectively control childhood asthma.^{5,9,36,37} The high cost of health care and the toll taken on children's health from this disease requires more work be done to establish effective and feasible interventions for the homes of asthmatic children. The impact of the indoor environment on asthma is undisputed^{6,26,38–42} and the time has come to better understand the means by which it can be monitored and IAQ improved. From our analysis we believe air quality for asthmatic children and children with mold allergies was improved in the majority of homes as reflected by the results of the health and QOL questionnaire data.

CONCLUSIONS

We believe that the data presented in this article support the hypothesis that simple, low-cost interventions can improve IAQ and lessen the symptoms of childhood asthma. We have shown improvement in scores for both asthma and allergy symptoms and general respiratory symptoms. By managing the fairly well understood causes of poor IAQ, we have shown that specific interventions can have a sustainable impact on the child's health. Therefore, standardized interventions aimed at improving IAQ are effective asthma management tools.

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