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## Journal of Asthma

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713597262>

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Online Publication Date: 01 July 2007

**To cite this Article** Peters, Junenette L., Levy, Jonathan I., Muilenberg, Michael L., Coull, Brent A. and Spengler, John D.(2007)'Efficacy of Integrated Pest Management in Reducing Cockroach Allergen Concentrations in Urban Public Housing',Journal of Asthma,44:6,455 — 460

**To link to this Article:** DOI: 10.1080/02770900701421971

**URL:** <http://dx.doi.org/10.1080/02770900701421971>

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ORIGINAL ARTICLE

# Efficacy of Integrated Pest Management in Reducing Cockroach Allergen Concentrations in Urban Public Housing

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The efficacy of residential interventions to reduce cockroach allergens in public housing developments was evaluated over months of follow-up. Repeated measurements were collected from 39 apartments, with longitudinal analyses used to evaluate changes over time. Blat kitchen concentrations were reduced 71% and bed concentrations 53% (86% and 70% for Blat 2, respectively) by 6 months post-intervention, after which concentrations began to increase. Apartments with higher concentrations were usually in poorer condition and benefited most from pest management efforts. Intensive interventions can significantly reduce the allergen burden in public housing apartments, but intervention efforts must be sustained.

**Keywords** asthma, cockroach allergen, community-based participatory research, low-income, intervention

## INTRODUCTION

Low-income, urban dwellers tend to be at greater risk of cockroach allergen sensitivity and elevated household cockroach allergen concentrations. This tendency has been suggested as a contributor to the relatively high incidence of asthma-related morbidity among inner-city children (1–4). Among urban populations in the northeastern United States, cockroach allergen sensitivity and exposure predominate, and in general, appear to have a greater effect on asthma morbidity than dust mite or pet allergens (5).

Public housing developments are designated as housing for low-to very-low-income households. In the northeastern United States, they are often located in low-income, minority neighborhoods and typically have persistent cockroach infestation. Public housing authorities have the capacity to implement comprehensive system-wide interventions. However, given the financial limitations faced by authorities, elucidating the optimal intensity, frequency, and timing for successful intervention and the areas of maximum benefit is critical.

Although allergen avoidance has been recommended as part of an asthma management plan (6–9), cockroach allergen reduction efforts using a variety of intervention measures have met with mixed results. Gergen et al. (10) focused on 48 homes that were part of the National Cooperative Inner-City Asthma Study (NCICAS), finding a significant reduction only in kitchen Blat 1 concentrations and only at 2 months after intervention. Concentrations increased to baseline levels or higher by month 12. Williams et al. (11) looked at eight

single-family dwellings and found a statistically significant reduction from baseline to month 6 for Blat 1, but not for Blat 2. These two studies primarily used pest control as the intervention method. Arbes et al. (12, 13) used a more comprehensive suite of interventions and found reductions over 6 months that could be sustained up to 12 months with additional pesticide treatment.

The current study is part of the Boston Healthy Public Housing Initiative (HPHI), a community-based participatory research project including collaborators from three universities, Boston city housing and health agencies, and associations representing tenants (see <http://www.hsph.harvard.edu/hphi/>). Our focus on the linkage between indoor allergens and asthma in public housing was motivated by an earlier survey of two of the developments that are part of this study that reported a prevalence of asthma more than double the Massachusetts average of 6.5% (14–17). In addition, allergy testing of asthmatic children in our study found that 59% of the children were allergic to cockroaches (18). A pilot study in nine apartments in one of our public housing developments found that intensive cleaning alone resulted in transient reductions in allergen concentrations (19), indicating the viability of this approach and the need for a more comprehensive assessment.

This study evaluates the effectiveness of a combination of abatement measures for reducing allergen concentrations and the factors affecting efficacy over months of follow-up.

## METHODS

### Population

We recruited families from three public housing developments in Boston, MA: Franklin Hill, Washington Beech, and West Broadway. To participate, a family had to include a child

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between 4 and 17 years of age who had self-reported doctor-diagnosed asthma. Asthma status was also evaluated by a study nurse and pediatric pulmonologist (18). Households received baseline environmental sampling between July 2002 and May 2003, with subsequent interventions aimed primarily at reducing pest-related allergen concentrations in apartment units. Post-intervention sampling took place between October 2002 and February 2004 at intervals immediately after and approximately 3, 6, 9, and 12 months after interventions. The time span reflects a two-phased recruitment process. Community Health Advocates from the developments or surrounding neighborhoods were trained and included as part of the study recruitment and data collection team. The study was approved by Boston University, Harvard School of Public Health and Tufts University institutional review boards. The required written, informed consent was obtained from all study participants.

### *Interventions*

Intervention activities included industrial cleaning, integrated pest management (IPM), and mattress replacement and are described in detail elsewhere (20). Briefly, industrial cleaning by contracted services involved the removal of cockroaches and mice and their feces and secretions and the removal of grease and debris. IPM included (1) laying mousetraps; (2) professional strategic placement of pest control treatments based on thorough inspection and sightings in cockroach traps; (3) sealing cracks and small holes that could be repaired using caulking and spray foam; (4) resident education on how to make the home inhospitable to pests; and (5) providing plastic food storage containers and trash bins. Residents were also encouraged to use the existing work-order system for requesting apartment maintenance services for more extensive repairs.

### *Allergen Analysis of Dust Samples*

Two separate vacuum dust samples were collected from each apartment—one from the child's bed and the other from the kitchen floor. The protocol for dust sample collection was based on the method outlined by Levy et al. (20) and Chew et al. (21). In brief, for bed samples, all layers of the bedding, including the mattress and pillows, were vacuumed for a total of five minutes. For kitchen samples, the cupboard under the kitchen sink and the kitchen floor, focusing on the baseboards and around the refrigerator and stove, were vacuumed for a total of five minutes.

For immunoassay analysis, 100 mg of sieved dust was extracted using 2 mL of borate buffered saline. Samples were analyzed for Bla g 1 and Bla g 2 cockroach allergens using a monoclonal sandwich enzyme-linked immunosorbent assay (ELISA) (Indoor Biotechnologies, Charlottesville, VA) (22). Concentrations are reported in U/g. The lower limits of detection (LLOD) were 0.20 U/g for Bla g 1 and 0.40 U/g for Bla g 2.

### *Statistics*

Values below the LLOD were assigned random numbers between zero and the LLOD according to an assumed uniform distribution. This gives less biased estimates than using fill-in methods such as LLOD or  $1/2$  LLOD (23). Days after

intervention were counted from the date of the last day of the multiple interventions, and then divided into months for analyses.

The efficacy and sustainability of interventions were assessed using three methods: (1) comparison of the difference between baseline and the minimum post-intervention concentration and of the difference between baseline and the final post-intervention concentration (Wilcoxon rank-sum test); (2) modeled trend in cockroach allergen concentrations over time (mixed model); and (3) odds of being below exacerbation levels over time (generalized estimating equations).

Mixed model longitudinal analysis was used on log-transformed continuous data to evaluate changes over time and the effect of household characteristics on these changes. Longitudinal analysis enabled us to account for the correlation among repeated measurements on the same household. This allowed for a more efficient use of the repeated measurements and provided information about time trends that would not be available through other summary statistics (i.e., paired *t* test). The mixed model is able to handle unbalanced data (missing data and variations in the timing of follow-up among participants) (24). We assumed that the correlation between repeated measures was best captured by compound symmetry, which assumes the same correlation between each of the measures in time, but tested other likely correlation structures. We allowed the baseline concentrations to vary by household (random intercept) instead of assuming that all households began at the group mean concentration. Time after intervention followed a quadratic form and was therefore modeled as month and month squared.

Concentrations were divided into categories based on the cut-point hypothesized to be associated with asthma exacerbation (8 U/g) (1, 25). The generalized estimating equations (GEE) method was used to assess the odds of being below this critical exacerbation level over the months post-intervention. This longitudinal method was used because the outcome was binary instead of continuous.

We considered housekeeping and presence of holes in the wall and ceiling as potential modifiers of the efficacy of interventions, based on a previous analysis that found both of these factors to be significant determinants of baseline cockroach allergen concentrations (26). Both variables were assessed during visual inspection of the apartments before interventions. Housekeeping was given a rating of one through five on the basis of cleanliness and clutter. For analysis, the five categories were reduced to two: below average housekeeping versus average to above average. Holes in the walls and ceilings were from a variety of sources including electrical installations and plumbing repairs. Season at sample collection was controlled for and was divided into cold months (October–April) and hot (May–September), roughly corresponding to the designated heating/non-heating seasons. *p* values less than 0.05 were considered significant, and less than 0.1 as marginally significant. All tests were performed using SAS software (version 9.1).

## RESULTS

Only data up to 10 months post-intervention were used in analyses because there were few measurements after that time. Of the 45 apartment units receiving interventions, 39

had at least one post-intervention measurement, 33 had 2, 26 had 3, and 17 had 4. Seventy-six percent of the 39 apartments with at least one post-intervention measurement had holes in the walls/ceiling. Thirteen percent had below average house-keeping practices (clutter and lack of cleanliness).

#### Effect of Intervention over Time

**Difference between baseline and minimum and between baseline and final post-intervention measures.** For kitchen allergen concentrations, there was a significant difference between a household's baseline value and minimum concentration after intervention, for both Bla g 1 and Bla g 2 ( $p < 0.01$ ) (Figure 1A; all figures show data for Bla g 1 only). The median difference was 23 U/g for Bla g 1 and 41 U/g for Bla g 2. Comparing the baseline concentrations with the final post-intervention measurement, the median differences were not as large (Bla g 1: 13 U/g; Bla g 2: 13 U/g), but the differences remained statistically significant (Bla g 1:  $p = 0.03$ ; Bla g 2:  $p = 0.04$ ).

Similarly, bed concentrations also decreased significantly between pre-intervention and minimum concentrations after intervention ( $p < 0.01$ ). The median reduction was 0.16 U/g for Bla g 1 and 1.3 U/g for Bla g 2 (Figure 1b). At the final post-intervention measurement, the difference for Bla g 1 was statistically significant ( $p = 0.01$ ), with a median reduction from baseline of 0.09 U/g. The difference for

Bla g 2 was only marginally significant ( $p = 0.05$ ), although the median reduction from baseline (0.87 U/g) did represent a reduction of greater than 50%. As above, the minimum concentrations after intervention were lower than at the final post-intervention measurement, indicating the potential for a U-shaped relationship between concentrations and time post-intervention.

**Trend of cockroach allergen concentrations post-intervention (mixed model).** Modeled geometric mean concentrations of Bla g 1 in the kitchen declined 71% from baseline to 6 months after the intervention (Figure 2a). At the lowest point, geometric mean concentrations were still above the asthma exacerbation cut-point of 8 U/g (at 9.6 U/g). Between month 6 and 10, the modeled geometric

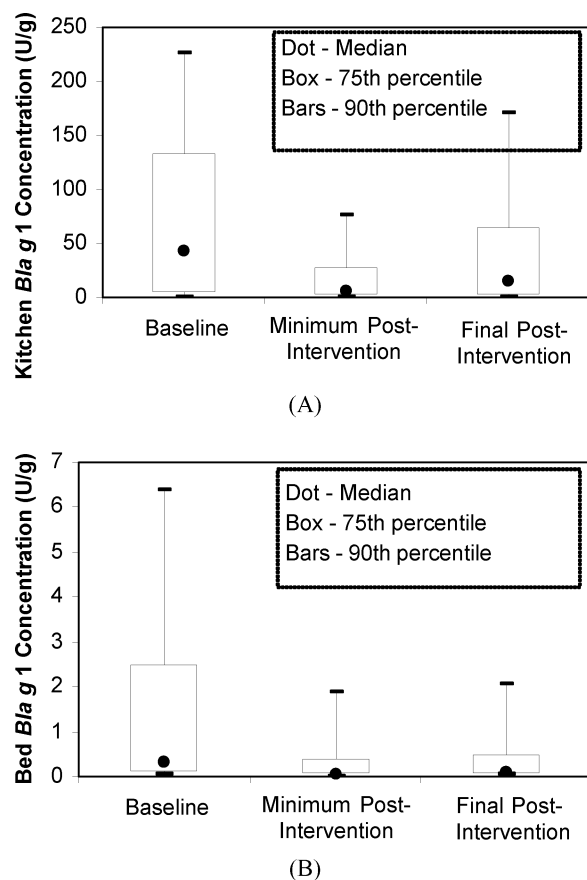


FIGURE 1.—Distribution of Bla g 1 cockroach allergen measurements at baseline, at minimum post-intervention levels, and at the final post-intervention measurement for (A) kitchen and (B) bed.

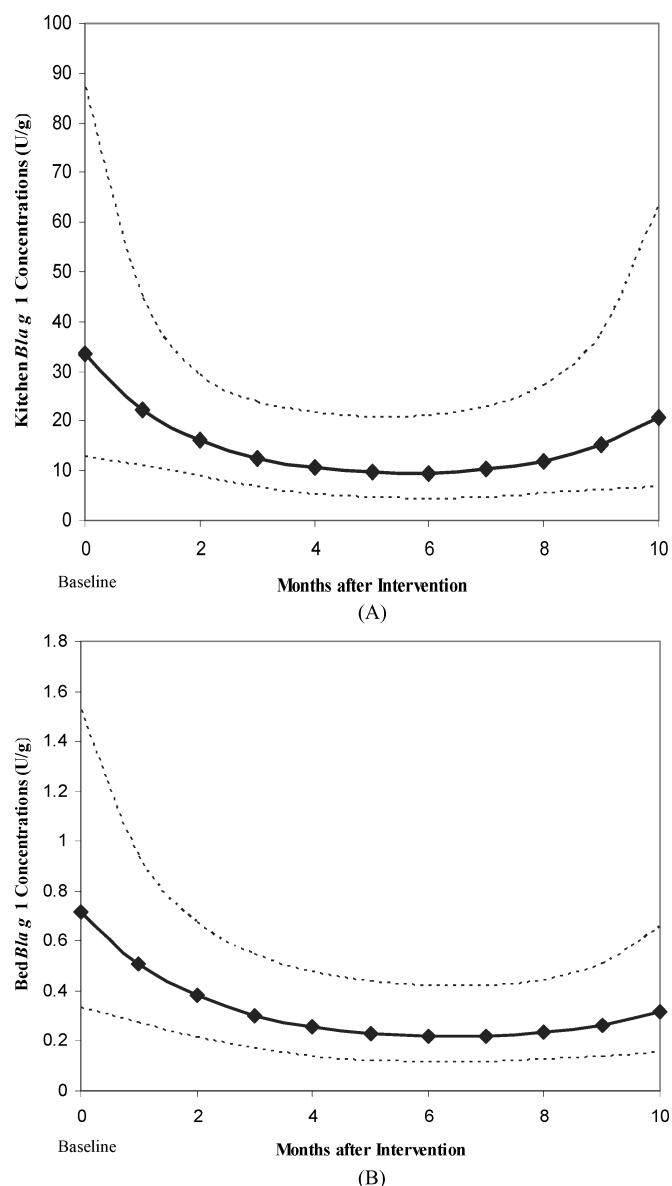


FIGURE 2.—Longitudinal mixed model (with random intercept) estimation of geometric mean and confidence intervals of (A) kitchen and (B) bed Bla g 1 concentrations with time after intervention. Month 0 represents baseline (pre-intervention).

mean concentrations started to increase so that, by month 10, concentrations were only 38% below baseline concentrations. Similarly, geometric mean Bla g 2 concentrations in the kitchen were reduced by 86% from baseline to 6 months after interventions, but concentrations then increased to 43% below baseline concentrations by month 10. Geometric mean concentrations of Bla g 2 also never fell below 8 U/g (at 17 U/g at the lowest point).

Similar trends were seen the bed, albeit with significantly lower concentrations (Figure 2b). Geometric mean concentrations of Bla g 1 in the bed were reduced 70% from baseline to 6 months post-intervention, but increased to 44% of baseline by month 10. Geometric mean Bla g 2 concentrations in the bed were reduced 53% by month 6, but increased to 16% below baseline by month 10.

*Odds of being below critical exacerbation level.* The mixed model analyses provide significant insight about changes in geometric mean concentrations, but the distribution of benefits is of equal importance, as it provides insight regarding the households where interventions were most effective and where health benefits might be anticipated. In particular, given the proposed critical asthma exacerbation level of 8 U/g, it is important to know whether the odds of being below this level changed over the post-intervention period. Despite the U-shaped relationship for geometric mean concentrations in mixed models, a quadratic term was not a statistically significant predictor of the odds of being below 8 U/g. Therefore, the odds ratios represent monthly changes in the odds of being below the exacerbation threshold throughout the study period. The odds ratio of being below the exacerbation cut-point by month after intervention was 1.17 (95% CI: 1.05–1.30) for Bla g 1 in the kitchen and 1.20 (95% CI: 1.08–1.34) for Bla g 2 in the kitchen. For bed concentrations, the odds ratio over time after intervention was not significant for Bla g 1 (0.99, 95% CI: 0.85–1.14), but was marginally significant (1.07, 95% CI: 0.99–1.16) for Bla g 2. Given the lower concentrations of cockroach allergens in the bed relative to the proposed exacerbation level of 8 U/g (especially for Bla g 1), the lack of significance is not surprising.

#### *Effect of Household Characteristics on Changes in Cockroach Allergen Concentrations over Time*

We examined whether there was a difference in change in allergen concentrations over time by housekeeping practices or holes in the walls and ceiling, controlling for season. In separate analyses, kitchen Bla g 1 had marginally greater reductions over time for those with below average housekeeping ( $p = 0.08$ ) and for those with holes in the walls/ceilings ( $p = 0.08$ ) at the start of the study. While the significance calculations are greatly affected by our unbalanced data set and lack of statistical power, all time trends indicated greater improvement among those apartments in poorer condition.

#### DISCUSSION

This study focused on the efficacy and sustainability of cockroach allergen reduction efforts applied in the public housing setting and the degree to which improvements depended on household conditions. We found that the combined environmental interventions of intensive cleaning and inte-

grated pest management, as well as new mattresses, were effective in reducing cockroach allergen concentrations in public housing. This is consistent with what has been documented from a review of cockroach allergen avoidance efforts (27). Apartments with higher allergen concentrations at baseline were usually in poorer condition with respect to housekeeping and holes in the wall/ceiling, and these apartments appeared to benefit most from the intervention efforts.

Both the traditional statistical method of comparison and longitudinal analysis gave us similar results. Both methods showed that allergen levels were reduced for a period of time after interventions but subsequently increased. However, the longitudinal analysis had four advantages over the Wilcoxon rank-sum test: (1) it allowed us to define the time horizon over which the allergen reduction and subsequent increase took place; (2) it let us use information from households even when they lacked measurements at each time point; (3) it avoided issues of multiple comparisons; and (4) it allowed us to formally consider variable responses across apartments. Longitudinal analysis showed that geometric mean allergen levels declined steadily for the first 6 months after intervention, after which point geometric mean concentrations began to increase. This information is of great interest to public housing authorities or other landlords attempting to address pest-related issues, as it indicates the frequency of pest management efforts needed.

Even with marked reductions in cockroach allergen concentrations, some apartments remained above concentrations that have the potential for exacerbating existing asthma. Other studies have reported similar findings, where concentrations were reduced significantly but remained above the hypothesized threshold (10, 12, 13, 28, 29). This may reflect the difficulty of eliminating the allergen reservoirs due to cockroach behavior patterns (7, 27). Nonetheless, as a result of our interventions, there were greater odds that an apartment would be below the proposed exacerbation cut-point for each month after intervention, despite increases in the geometric mean concentrations after 6 months post-intervention. This observation of an increase in geometric means after 6 months versus the linear decrease in odds of being below the cut-point may reflect improvements in a growing number of homes, while a few homes may have reverted to high concentrations thus driving up the mean.

While this analysis reports on reductions relative to an exacerbation cut-point, it should be noted that the effect of allergen concentrations on asthma exacerbation occurs along a continuum rather than at a sharply defined threshold (30). This suggests that even modest reductions in concentrations may benefit especially sensitive asthmatics. In addition, reductions of concentrations already below proposed thresholds could improve allergen-related symptoms. Morgan et al. (31) reported geometric mean bed concentrations below critical sensitization and exacerbation levels, similar to what was observed in our study for Bla g 1. They found that a reduction in these relatively low cockroach allergen concentrations significantly correlated with a decrease in asthma-related morbidity. In another analysis of our cohort, reduction in cockroach allergen concentrations was moderately associated with improvements in some respiratory outcomes (20) as well as quality of life (32).

Because of our small sample size, we may not have had the power to detect differential effects by housekeeping practices or presence of holes in the wall. However, the directions of the effects were consistent with expectations given our combination of interventions. We were unable to repair major holes in the walls in this study; however, our pest management activities included integrated pest management techniques addressing sources of food, water, and shelter for cockroaches, which may have limited entry of roaches from other units.

We conclude that cockroach allergen can be reduced in individual public housing units through intensive cleaning and integrated pest management and that the reductions can be sustained up to 6 months with no further external intervention. However, since cockroach populations can most likely be controlled, not eliminated, strategic placement of pest control treatment based on visual inspection and cockroach traps should be instituted as part of the work orders for regularly scheduled extermination visits in the developments. These efforts should preferably be done on a building-wide basis to minimize the likelihood of reinfestation and should follow integrated pest management principles to minimize residential pesticide exposures. Coupled with an educational campaign, this might provide long-term, sustainable cockroach allergen reductions. Given the high prevalence of asthma and frequency of cockroach allergen sensitivities among asthmatics in this population, intervention efforts may play a key role in reducing asthma-related morbidity.

#### ACKNOWLEDGMENT

The authors wish to thank the community health advocates and those who worked with them in data collection and outreach. In addition, they thank Jose Vallarino, Research Specialist at the Harvard School of Public Health, for his invaluable contributions to data collection efforts. They also thank the Simmons Inc. for the allergy-free mattresses. Most importantly, the authors thank the families from the three public housing developments who participated in the study.

HPHI partners included Boston Housing Authority, Boston Public Health Commission, Boston University School of Public Health, Committee for Boston Public Housing, Franklin Hill Tenant Task Force, Inc., Harvard University School of Public Health, Peregrine Energy Group, Tufts University School of Medicine, Urban Habitat Initiatives, and West Broadway Tenant Task Force, Inc.

Funding for this study was received from the U.S. Department of Housing and Urban Development's Office of Healthy Homes and Lead Hazard Control (Grant MALHH0077-00), W. K. Kellogg Foundation, Jessie B. Cox Family Trust, and The Boston Foundation. J.L.P. was funded in part by the NIEHS Training Grant 2T32HL07118-29 and Center Grant P30 ES00002.

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