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Pest and allergen exposure and abatement in inner-city asthma: A Work Group Report of the American Academy of Allergy, Asthma & Immunology Indoor Allergy/Air Pollution Committee

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Abstract

Our work group report details the importance of pest allergen exposure in inner-city asthma. We will focus specifically on mouse and cockroach exposure. We will discuss how exposure to these pests is common in the inner city and what conditions exist in urban areas that might lead to increased exposure. We will discuss how exposure is associated with allergen sensitization and asthma morbidity. Finally, we will discuss different methods of intervention and the effectiveness of these tactics.

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Keywords

Asthma; allergies; environmental allergens; indoor allergens; pest; rodents; inner city; abatement; mouse; cockroach

The prevalence of asthma in developed countries has been increasing in recent decades. This increase has been particularly noted in urban areas, where up to 1 in 4 children might be affected by asthma.¹ Environmental factors, including cigarette smoke, air pollution, and allergen exposure, combine to contribute to asthma morbidity. Additionally, inner-city inhabitants might not be knowledgeable of the association of indoor allergen exposures with asthma.² Apart from possible differences in socioeconomic status, urban areas provide a unique setting for asthma because of certain environmental conditions existing in the inner city. In this work group report we will discuss the importance of insect and rodent allergen exposure in inner-city asthma. Specifically, we will focus on mouse and cockroach allergen exposure, their effects on asthma, and reduction tactics in the inner city.

Previously, there have been many review articles focusing on the overall effect of all indoor allergens.^{3–5} However, in recent years, there has been an increasing amount of research devoted specifically to exposure to insects and rodents as a major factor contributing to asthma morbidity in urban areas. Numerous studies have documented high levels of mouse (Mus m 1 and mouse urinary protein [MUP]), rat (Rat n 1), and cockroach (Bla g 1 and Bla g 2) allergens in dust samples from urban homes, schools, and day care centers.

PEST ALLERGENS: DISTRIBUTION AND EPIDEMIOLOGY

Cockroach and mouse allergens have been detected in homes and schools of inner-city areas of multiple US cities

Initial studies in inner-city homes focused on the presence of cockroach allergen, and then subsequent studies evaluated mouse and rat allergens. The National Cooperative Inner-City Asthma Study (NCICAS) was the first National Institutes of Health–funded, multicenter, inner-city effort to understand the role of the environment in childhood asthma in the United States.⁶ The NCI-CAS measured cockroach allergen (Bla g 1) in collected dust from children's bedrooms and found that 85.3% had detectable levels and 50.2% had what were considered high levels (>8 U/g).⁶ More recently, studies in individual cities have shown 98% of homes in Gary, Indiana, with detectable cockroach allergen⁷ and 56.6% of homes in New Orleans with high levels of cockroach allergen.⁸

Subsequently, Phipatanakul et al⁹ reported that 95% of all the NCICAS homes had detectable levels of mouse allergen (Mus m 1) in at least one room, with the highest levels found in kitchens. Similarly, it was discovered that 33% of the inner-city homes in the NCICAS had detectable levels of rat allergen.¹⁰ In these homes the presence of mouse and rat allergens was associated with reported rat and mouse infestation.¹⁰ After these data, Phipatanakul et al¹¹ reported 42% of homes in Boston with detectable mouse allergen, and Matsui et al¹² reported that Mus m 1 was detectable in bedroom air samples among 84% of children with asthma living in Baltimore.

Expanding on these data, the Inner-City Asthma Study (ICAS) found more than 50% of homes in New York and Chicago had Bla g 1 levels greater than 2 U/g.¹³ This same study found evidence of cockroaches in 62.0% and evidence of mice or rats in 23.3% of studied homes.¹³ Likewise, Chew et al¹⁴ found evidence of cockroaches in 77% and evidence of mice in 13% of public housing residences in New York City. It is expected that levels of pest allergens will vary between cities, as evidenced by both the NCICAS and ICAS cohorts.^{6,9,13} However,

Simons et al¹⁵ demonstrated significantly higher rates of pest infestation and significantly higher levels of mouse and cockroach allergen in inner-city homes compared with levels found in suburban homes in the same city.

The presence of cockroach allergen is not isolated to homes but also exists in urban schools. Chew et al¹⁶ found detectable levels of cockroach allergen (Bla g 2) in 71% of dust samples collected from 11 urban high schools. In the analysis of schoolrooms in Detroit, Houston, and Birmingham, Alabama, Abramson et al¹⁷ found all 3 cities contained schoolrooms with levels of cockroach allergen exceeding proposed sensitization thresholds. Similar results were found in 2 separate studies in Baltimore city schools.^{18,19} A study of 2 inner-city elementary schools in Minneapolis discovered the median cockroach allergen (Bla g 1) level to be approximately 1 U/g.²⁰ Sheehan et al²¹ found 89% of dust samples from 4 inner-city schools contained detectable levels of mouse allergen (MUP). Interestingly, this study demonstrated that the school samples had significantly higher levels of MUP when compared with students' homes in the same city, although selection of the students who volunteered for the study might have introduced bias.²¹ Pest allergens have not only been found in schools but also in day care centers. Arbes et al²² studied multiple day care centers in 2 North Carolina counties and found 52% of samples with detectable cockroach allergen and 83% with detectable mouse allergen. A similar study of Head Start facilities in Arkansas revealed 100% with detectable mouse allergen.²³ This study had fewer centers with detectable cockroach allergen, but only a minority of the centers were in urban locations.

RISK FACTORS FOR PEST ALLERGEN EXPOSURE

Inner-city conditions contribute to allergen exposure

Certain factors prevalent in inner-city areas of the United States have been associated with higher levels of mouse and cockroach infestation and subsequent exposure to these indoor allergens. These factors are mainly housing related, but it is often difficult to tease apart the social demographics, such as lower income, lower level of education, black race, and Hispanic ethnicity, that have also been associated with increased risk of allergen exposure.^{11,24–29} In addition, high population density areas, such as multifamily homes and high-rise apartment buildings, have been associated with higher levels of mouse and cockroach allergen.^{13,26,27,30} This is particularly true of older cities with aged and deteriorating systems (eg, gas, water and sewer, electrical, subway, and highways). Finally, deterioration of the physical condition of homes has been identified as a predictor. For example, higher mouse and cockroach exposure has been associated with increased clutter, water damage, and the presence of cracks or holes in ceilings or walls.^{12,30–34} Furthermore, stone foundations that can harbor rodents, the uneven settling of older foundations, and vacant lots contribute to pest infestation. In many urban areas the combination of lower socioeconomic status, high population density, and poor physical condition of buildings provides the unfortunate ideal setting for cockroach and rodent infestation.

DIAGNOSIS OF PEST ALLERGY

Diagnostic tests for cockroach and mouse allergen sensitization include skin prick testing, intradermal testing, and *in vitro* tests for allergen-specific antibodies. Although evaluation for cockroach sensitization has been standard for some time, there have been recent advances in diagnostic approaches to patients with suspected mouse allergy.^{35–38} Despite recent advances in blood tests for mouse allergy, Sharma et al³⁵ demonstrated that skin prick tests are the most useful in discriminating patients with and without mouse allergy. This was the first study to evaluate currently available diagnostic tests for mouse allergy. It should be noted that this study was performed in a population of laboratory workers, and therefore the diagnostic performance

of these tests in an inner-city population of asthmatic subjects is not known. Finally, it is important to note that currently available mouse extracts are not standardized.

PEST ALLERGEN EXPOSURE AND SENSITIZATION

Exposure to pest allergens has been associated with sensitization

Exposure to these allergens is troubling; however, an understanding of the role of exposure in the development of allergic sensitization is important. In 1964, Bernton and Brown³⁹ reported that 44% of allergic clinic patients living in New York were sensitized to cockroach. Through a combination of standard and more recent diagnostic techniques, it has been demonstrated that exposure to mouse and cockroach antigen, especially in urban areas, is associated with allergic sensitization in patients with asthma. In general, subjects from homes with higher levels of cockroach or mouse allergen exposure have higher rates of specific allergen sensitization. The first group to demonstrate this association was the multicity NCICAS. Eggleston et al⁴⁰ demonstrated that bedroom concentrations of Bla g 1 were related to cockroach sensitization in children with asthma, as determined by means of skin testing. After this, the same cohort was used to demonstrate that asthmatic children from homes with higher mouse allergen concentrations had significantly higher rates of mouse sensitization.⁴¹ A different multicenter trial confirmed these previous findings when Huss et al⁴² noted that children with asthma from homes with cockroach allergen exposure were twice as likely to have a positive skin test response to cockroach allergen. The association of exposure and sensitization has been documented in suburban settings, as well as inner-city areas.^{43,44} Recently, Chew et al⁴⁵ studied home environments of inner-city children in a population-based study (ie, children with and without asthma) and found a dose-response relationship between home Bla g 2 exposure and cockroach sensitization. It has even been theorized that prenatal exposure to pest allergens can lead to sensitization. A study of newborns in New York City suggested that there are high prenatal exposures to cockroach and mouse allergens. Increased mononuclear cell proliferation occurred in 54% of newborns in response to cockroach and 34% in response to mouse protein extracts.⁴⁶ This suggests that prenatal exposure to cockroach and mouse allergens might be able to prime the immune system of fetuses before birth and possibly contribute to the development of allergies.

PEST ALLERGENS AND ASTHMA

Exposure to pest allergens in the inner city has been demonstrated to have clinical effects in regard to asthma

Exposure to cockroach, mouse, and rat allergens is associated with wheezing and asthma morbidity, especially in subjects who are sensitized. Initially, studies by Kang⁴⁷ demonstrated that inhalation of cockroach extract caused a significant decrease in lung function for asthmatic subjects with cockroach allergy. Rosenstreich et al⁶ further studied this in the NCICAS. These authors discovered that inner-city children with asthma who were sensitized to cockroach and exposed to cockroach allergen in high levels (>8 U/g) had higher asthma morbidity, including more hospitalizations, more medical visits, and more reported symptoms. Findings from the ICAS agreed with these results in demonstrating that the combination of cockroach exposure and sensitization was associated with asthma morbidity.¹³ A study from inner-city Baltimore showed a similar trend for mouse exposure. Children with mouse allergy and high levels of home mouse allergen exposure (Mus m 1 >0.5 μ g/g) were more likely to have unscheduled physician visits, emergency department visits, and hospitalizations.⁴⁸ These findings were confirmed in a recently published multicenter trial by the ICAS.⁴⁹ Rat allergen has also been implicated in asthma morbidity. Rat allergen was detected in 33% of homes in the NCICAS, and rat-sensitized children who had detectable rat allergen in their homes had greater asthma morbidity.⁵⁰

Multiple studies in recent years have confirmed the association between cockroach and mouse exposure and asthma morbidity. Household exposure to cockroaches and mice has been shown to be associated with higher rates of asthma in inner-city areas both within the United States and in other countries.^{7,14,29,51–53} Exposure to cockroach allergen has also been shown to be associated with persistent childhood wheezing⁵⁴ and severe asthma.⁵⁵ Exposure to both cockroach and mouse allergen at an early age was independently associated with the development of wheeze in the first year of life⁵⁶ and later in childhood.^{57,58}

The association of inner-city pest allergen exposure and asthma morbidity has not been thoroughly studied in adults. Phipatanakul et al⁵⁹ reported a study of adult women in whom sensitization to mouse allergen was, in fact, associated with more than twice the odds of asthma diagnosis. However, additional studies in adults are needed in this area.

PEST ALLERGEN ABATEMENT

Allergen reduction tactics have been shown to successfully reduce allergen levels, and more recent studies have demonstrated improved asthma symptoms

Different techniques have been implemented for pest removal in urban homes in attempts to potentially reduce pest-related morbidity. Pest allergens appear to be particularly difficult to eliminate and require different strategies than those used for other indoor allergens. These interventions include initial removal of the insects, rodents, or both but also require long-term care to prevent a return of the infestation. A variety of methods aim to eliminate the allergen source and continue to keep low levels of allergens in the home, including thorough cleaning, education on allergen removal, use of air filters, filling of holes, application of insecticides and rodenticides, traps, bait stations, and professional extermination. After the initial extermination process, long-term elimination is focused on intensive cleaning and sealing of cracks and holes in the foundation and infrastructure of homes. These breaks in walls and around utility systems can be sealed with caulking, metal mesh, or expandable spray foams and gels. The combination of control tactics is often called integrated pest management (IPM). A list of allergen reduction techniques is provided in Table I. Further details on methods of IPM have been previously reviewed and are included as references.^{60–63}

The initial intervention of allergen removal generally involves pesticides, such as insecticides or rodenticides. This process can be done by means of professional methods, such as commercial cleaning and extermination. In some cases inner-city inhabitants have turned to illegal methods to try to eliminate pests. In a recent study 15% of inhabitants in New York City public housing reported using illegal pesticides.¹⁴ The use of illegal pesticides is concerning because pesticide exposure has been associated with a higher prevalence of atopic diseases, chronic bronchitis, and possible decreased lung function.^{64–67} Bait stations and baited traps can also be used with and without pesticides. McConnell et al⁶⁸ demonstrated that cockroach allergen was most effectively reduced by the combination of professional cleaning and baited traps with insecticide. Interestingly, in this study professional cleaning with baited traps but without insecticide was effective in reducing cockroach allergen in kitchens of homes with higher initial levels. Similar studies in different areas of the United States demonstrated the success of professional cleaning with insecticides to reduce cockroach allergen levels.^{69–72} The use of high-efficiency particulate air (HEPA) filters and vacuums can also provide assistance in addition to extermination by reducing airborne particles containing cockroach allergen. Eggleston et al⁷³ used a combination of home-based education, cockroach extermination, and HEPA filters to reduce cockroach allergen levels by 51%. A different study demonstrated that this combination was successful at reducing cockroach allergen for up to 1 year after the monitored intervention trial.⁷⁴ Although professional cleaning has been shown to be successful, one study demonstrated a difference between pest control delivered by a professional entomologist compared with commercial companies. Sever et al⁷⁵ reported

prolonged (12 months after intervention) reductions in cockroach allergen in homes exterminated by academic entomologists, but a lack of prolonged reduction in homes treated by commercial companies.

Although most interventional studies have focused on cockroach allergen reduction, Phipatanakul et al⁷⁶ used IPM to reduce mouse allergen in Boston homes. This study used a combination of hole filling with copper mesh, vacuuming, cleaning, and the use of baited traps with low-toxicity pesticides. With these techniques, researchers were able to significantly decrease *Mus m 1* levels by greater than 75% in kitchens and bedrooms. More recently, researchers from the ICAS also showed that IPM was successful at significantly reducing bedroom floor mouse allergen levels.⁴⁹

The importance of allergen reduction is to ultimately examine whether this reduction improves health outcomes. In recent years, there have been more studies examining the efficacy of insect and rodent pest removal not only to decrease allergen levels but also to improve asthma symptoms. This provides the beneficial link between environmental intervention and improved health outcomes. Researchers from the ICAS were the first to demonstrate that environmental interventions reduced asthma symptoms.⁷⁴ They demonstrated that 1 year of controlled intervention tactics (professional cleaning, bait traps, insecticides, and HEPA filters) was able to reduce cockroach allergen levels and that these improvements were significantly correlated with decreased wheeze, decreased nighttime asthma symptoms, and fewer missed school days.⁷⁴ These clinical improvements persisted for 1 year after the monitored environmental intervention had ceased.⁷⁴ In a similar study Eggleston et al⁷³ used environmental interventions to reduce cockroach allergen and, subsequently, reduce daytime asthma symptoms.

Most recently, Pongracic et al⁴⁹ showed that integrated interventions were effective in reducing mouse allergen levels on the bedroom floor. In this study mouse allergen reduction was associated with reduced missed school days, reduced sleep disruption, and reduced caretaker burden. In accordance with these studies, the ICAS has shown that home-based intervention strategies are cost-effective for inner-city asthma by reducing asthma symptoms days and the associated costs.⁷⁷ A summary of successful studies on interventions to reduce allergen exposure is presented in Table II.^{49,68–76}

There are relatively few studies focusing on the long-term outcomes or side effects of pest allergen reduction. There is concern about the long-term efficacy of integrated interventions. Morgan et al⁷⁴ demonstrated reduced allergen exposure and improved asthma symptoms for 1 year after interventions. In contrast to this, an earlier study from the NCICAS showed that the decrease in cockroach allergen was evident 6 months after interventions but that levels had returned to baseline 12 months after interventions.⁶⁹ As noted previously, Sever et al⁷⁵ found a significant reduction in cockroach allergen 12 months after interventions performed by professional entomologists but no reduction at 12 months after intervention by a commercial pest removal company. This demonstrates that continuous efforts (professionally or family directed) to eliminate these allergens might be necessary for sustained cockroach allergen reduction. Similar long-term studies are needed on the reduction of rodent allergen.

CONCLUSIONS AND FUTURE RESEARCH

Future research in this field will continue to evaluate the effectiveness of inner-city allergen reduction in improving the health outcomes of asthma. Most of the studies to date have focused on pediatric asthma, but it is important to expand these hypotheses to adult asthma. Additionally, future long-term research must strive to evaluate or create methods that will maintain reduced allergen levels over time, even after professional interventions have ceased.

This long-term reduction will likely require community-wide and not just individual residence control interventions. Finally, although most of the studies to date have evaluated homes as the source of allergen exposure, it is important that other environments, such as schools and workplaces in the inner city, also be studied.

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Abbreviations used

HEPA	High-efficiency particulate air
ICAS	Inner-City Asthma Study
IPM	Integrated pest management
MUP	Mouse urinary protein
NCICAS	National Cooperative Inner-City Asthma Study

REFERENCES

1. Lilly CM. Diversity of asthma: evolving concepts of pathophysiology and lessons from genetics. *J Allergy Clin Immunol* 2005;115:S526–S531. [PubMed: 15806035]
2. Malone AM, Gupta RS, Lyttle CS, Weiss KB. Characterizing community-based asthma knowledge in Chicago and its high risk neighborhoods. *J Asthma* 2008;45:313–318. [PubMed: 18446596]
3. Platts-Mills T, Leung DY, Schatz M. The role of allergens in asthma. *Am Fam Physician* 2007;76:675–680. [PubMed: 17894137]
4. Sharma HP, Hansel NN, Matsui E, Diette GB, Eggleston P, Breyse P. Indoor environmental influences on children's asthma. *Pediatr Clin North Am* 2007;54:103–120. ix. [PubMed: 17306686]
5. Phipatanakul W. Environmental factors and childhood asthma. *Pediatr Ann* 2006;35:646–556. [PubMed: 16999298]
6. Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin RG, Gergen P, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *N Engl J Med* 1997;336:1356–1363. [PubMed: 9134876]
7. Wang C, Abou El-Nour MM, Bennett GW. Survey of pest infestation, asthma, and allergy in low-income housing. *J Community Health* 2008;33:31–39. [PubMed: 18080206]
8. Rabito FA, Iqbal S, Holt E, Grimsley LF, Islam TM, Scott SK. Prevalence of indoor allergen exposures among New Orleans children with asthma. *J Urban Health* 2007;84:782–792. [PubMed: 17917814]
9. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. Mouse allergen. I. The prevalence of mouse allergen in inner-city homes. The National Cooperative Inner-City Asthma Study. *J Allergy Clin Immunol* 2000;106:1070–1074. [PubMed: 11112888]
10. Perry T, Matsui E, Merriman B, Duong T, Eggleston P. The prevalence of rat allergen in inner-city homes and its relationship to sensitization and asthma morbidity. *J Allergy Clin Immunol* 2003;112:346–352. [PubMed: 12897741]
11. Phipatanakul W, Gold DR, Muilenberg M, Sredl DL, Weiss ST, Celedon JC. Predictors of indoor exposure to mouse allergen in urban and suburban homes in Boston. *Allergy* 2005;60:697–701. [PubMed: 15813819]
12. Matsui EC, Simons E, Rand C, Butz A, Buckley TJ, Breyse P, et al. Airborne mouse allergen in the homes of inner-city children with asthma. *J Allergy Clin Immunol* 2005;115:358–363. [PubMed: 15696095]

13. Gruchalla RS, Pongratic J, Plaut M, Evans R 3rd, Visness CM, Walter M, et al. Inner City Asthma Study: relationships among sensitivity, allergen exposure, and asthma morbidity. *J Allergy Clin Immunol* 2005;115:478–485. [PubMed: 15753892]
14. Chew GL, Carlton EJ, Kass D, Hernandez M, Clarke B, Tiven J, et al. Determinants of cockroach and mouse exposure and associations with asthma in families and elderly individuals living in New York City public housing. *Ann Allergy Asthma Immunol* 2006;97:502–513. [PubMed: 17069106]
15. Simons E, Curtin-Brosnan J, Buckley T, Breyse P, Eggleston PA. Indoor environmental differences between inner city and suburban homes of children with asthma. *J Urban Health* 2007;84:577–590. [PubMed: 17551839]
16. Chew GL, Correa JC, Perzanowski MS. Mouse and cockroach allergens in the dust and air in northeastern United States inner-city public high schools. *Indoor Air* 2005;15:228–234. [PubMed: 15982269]
17. Abramson SL, Turner-Henson A, Anderson L, Hemstreet MP, Bartholomew LK, Joseph CL, et al. Allergens in school settings: results of environmental assessments in 3 city school systems. *J Sch Health* 2006;76:246–249. [PubMed: 16918848]
18. Amr S, Bollinger ME, Myers M, Hamilton RG, Weiss SR, Rossman M, et al. Environmental allergens and asthma in urban elementary schools. *Ann Allergy Asthma Immunol* 2003;90:34–40. [PubMed: 12546335]
19. Sarpong SB, Wood RA, Karrison T, Eggleston PA. Cockroach allergen (Bla g 1) in school dust. *J Allergy Clin Immunol* 1997;99:486–492. [PubMed: 9111492]
20. Ramachandran G, Adgate JL, Banerjee S, Church TR, Jones D, Fredrickson A, et al. Indoor air quality in two urban elementary schools—measurements of airborne fungi, carpet allergens, CO₂, temperature, and relative humidity. *J Occup Environ Hyg* 2005;2:553–566. [PubMed: 16223714]
21. Sheehan WJ, Rangsihienchai PA, Muilenberg ML, Rogers CA, Lane JP, Ghaemghami J, et al. Mouse allergens in urban elementary schools and homes of children with asthma. *Ann Allergy Asthma Immunol* 2009;102:125–130. [PubMed: 19230463]
22. Arbes SJ, Sever M, Mehta J, Collette N, Thomas B, Zeldin DC. Exposure to indoor allergens in day-care facilities: results from 2 North Carolina counties. *J Allergy Clin Immunol* 2005;116:133–139. [PubMed: 15990786]
23. Perry TT, Vargas PA, Bufford J, Feild C, Flick M, Simpson PM, et al. Classroom aeroallergen exposure in Arkansas head start centers. *Ann Allergy Asthma Immunol* 2008;100:358–363. [PubMed: 18450122]
24. Wright RJ, Subramanian SV. Advancing a multilevel framework for epidemiologic research on asthma disparities. *Chest* 2007;132:757S–769S. [PubMed: 17998340]
25. Kitch BT, Chew G, Burge HA, Muilenberg ML, Weiss ST, Platts-Mills TA, et al. Socioeconomic predictors of high allergen levels in homes in the greater Boston area. *Environ Health Perspect* 2000;108:301–307. [PubMed: 10753087]
26. Cohn RD, Arbes SJ Jr, Jaramillo R, Reid LH, Zeldin DC. National prevalence and exposure risk for cockroach allergen in U.S. households. *Environ Health Perspect* 2006;114:522–526. [PubMed: 16581539]
27. Leaderer BP, Belanger K, Triche E, Holford T, Gold DR, Kim Y, et al. Dust mite, cockroach, cat, and dog allergen concentrations in homes of asthmatic children in the northeastern United States: impact of socioeconomic factors and population density. *Environ Health Perspect* 2002;110:419–425. [PubMed: 11940461]
28. Teach SJ, Crain EF, Quint DM, Hylan ML, Joseph JG. Indoor environmental exposures among children with asthma seen in an urban emergency department. *Pediatrics* 2006;117:S152–S158. [PubMed: 16777831]
29. Salo PM, Arbes SJ Jr, Crockett PW, Thorne PS, Cohn RD, Zeldin DC. Exposure to multiple indoor allergens in US homes and its relationship to asthma. *J Allergy Clin Immunol* 2008;121:678–684. e2. [PubMed: 18255132]
30. Bradman A, Chevrier J, Tager I, Lipsett M, Sedgwick J, Macher J, et al. Association of housing disrepair indicators with cockroach and rodent infestations in a cohort of pregnant Latina women and their children. *Environ Health Perspect* 2005;113:1795–1801. [PubMed: 16330367]

31. Peters JL, Levy JI, Rogers CA, Burge HA, Spengler JD. Determinants of allergen concentrations in apartments of asthmatic children living in public housing. *J Urban Health* 2007;84:185–197. [PubMed: 17216349]
32. Chew GL, Perzanowski MS, Miller RL, Correa JC, Hoepner LA, Jusino CM, et al. Distribution and determinants of mouse allergen exposure in low-income New York City apartments. *Environ Health Perspect* 2003;111:1348–1351. [PubMed: 12896857]
33. Rauh VA, Chew GR, Garfinkel RS. Deteriorated housing contributes to high cockroach allergen levels in inner-city households. *Environ Health Perspect* 2002;110:323–327. [PubMed: 11929744]
34. Berg J, McConnell R, Milam J, Galvan J, Kotlerman J, Thorne P, et al. Rodent allergen in Los Angeles inner city homes of children with asthma. *J Urban Health* 2008;85:52–61. [PubMed: 18004665]
35. Sharma HP, Wood RA, Bravo AR, Matsui EC. A comparison of skin prick tests, intradermal skin tests, and specific IgE in the diagnosis of mouse allergy. *J Allergy Clin Immunol* 2008;121:933–939. [PubMed: 18325579]
36. Platts-Mills TA, Satinover SM, Naccara L, Litonjua AA, Phipatanakul W, Carter MC, et al. Prevalence and titer of IgE antibodies to mouse allergens. *J Allergy Clin Immunol* 2007;120:1058–1064. [PubMed: 17767949]
37. Matsui EC, Eggleston PA, Breyse PN, Rand CS, Diette GB. Mouse allergen-specific antibody responses in inner-city children with asthma. *J Allergy Clin Immunol* 2007;119:910–915. [PubMed: 17337296]
38. Krop EJ, Matsui EC, Sharrow SD, Stone MJ, Gerber P, van der Zee JS, et al. Recombinant major urinary proteins of the mouse in specific IgE and IgG testing. *Int Arch Allergy Immunol* 2007;144:296–304. [PubMed: 17652940]
39. Bernton HS, Brown H. Insect allergy—preliminary studies of the cockroach. *J Allergy Clin Immunol* 1964;35:506–513. [PubMed: 14226309]
40. Eggleston PA, Rosenstreich D, Lynn H, Gergen P, Baker D, Kattan M, et al. Relationship of indoor allergen exposure to skin test sensitivity in inner-city children with asthma. *J Allergy Clin Immunol* 1998;102:563–570. [PubMed: 9802363]
41. Phipatanakul W, Eggleston PA, Wright EC, Wood RA. Mouse allergen. II. The relationship of mouse allergen exposure to mouse sensitization and asthma morbidity in inner-city children with asthma. *J Allergy Clin Immunol* 2000;106:1075–1080. [PubMed: 11112889]
42. Huss K, Adkinson NF Jr, Eggleston PA, Dawson C, Van Natta ML, Hamilton RG. House dust mite and cockroach exposure are strong risk factors for positive allergy skin test responses in the Childhood Asthma Management Program. *J Allergy Clin Immunol* 2001;107:48–54. [PubMed: 11149990]
43. Matsui EC, Wood RA, Rand C, Kanchanaraks S, Swartz L, Curtin-Brosnan J, et al. Cockroach allergen exposure and sensitization in suburban middle-class children with asthma. *J Allergy Clin Immunol* 2003;112:87–92. [PubMed: 12847484]
44. Matsui EC, Wood RA, Rand C, Kanchanaraks S, Swartz L, Eggleston PA. Mouse allergen exposure and mouse skin test sensitivity in suburban, middle-class children with asthma. *J Allergy Clin Immunol* 2004;113:910–915. [PubMed: 15131574]
45. Chew GL, Perzanowski MS, Canfield SM, Goldstein IF, Mellins RB, Hoepner LA, et al. Cockroach allergen levels and associations with cockroach-specific IgE. *J Allergy Clin Immunol* 2008;121:240–245. [PubMed: 17936887]
46. Miller RL, Chew GL, Bell CA, Biedermann SA, Aggarwal M, Kinney PL, et al. Prenatal exposure, maternal sensitization, and sensitization in utero to indoor allergens in an inner-city cohort. *Am J Respir Crit Care Med* 2001;164:995–1001. [PubMed: 11587985]
47. Kang B. Study on cockroach antigen as a probable causative agent in bronchial asthma. *J Allergy Clin Immunol* 1976;58:357–365. [PubMed: 965615]
48. Matsui EC, Eggleston PA, Buckley TJ, Krishnan JA, Breyse PN, Rand CS, et al. Household mouse allergen exposure and asthma morbidity in inner-city preschool children. *Ann Allergy Asthma Immunol* 2006;97:514–520. [PubMed: 17069107]
49. Pongracic JA, Visness CM, Gruchalla RS, Evans R 3rd, Herman EM. Effect of mouse allergen and rodent environment intervention on asthma in inner-city children. *Ann Allergy Asthma Immunol* 2008;101:35–41. [PubMed: 18681082]

50. Perry T, Matsui E, Merriman B, Duong T, Eggleston P. The prevalence of rat allergen in inner-city homes and its relationship to sensitization and asthma morbidity. *J Allergy Clin Immunol* 2003;112:346–352. [PubMed: 12897741]
51. Sarinho E, Schor D, Veloso MA, Rizzo JA. There are more asthmatics in homes with high cockroach infestation. *Braz J Med Biol Res* 2004;37:503–510. [PubMed: 15064813]
52. Turyk M, Curtis L, Scheff P, Contreras A, Coover L, Hernandez E, et al. Environmental allergens and asthma morbidity in low-income children. *J Asthma* 2006;43:453–457. [PubMed: 16952864]
53. Salo PM, Jaramillo R, Cohn RD, London SJ, Zeldin DC. Exposure to mouse allergen in U.S. homes associated with asthma symptoms. *Environ Health Perspect* 2009;117:387–391. [PubMed: 19337513]
54. Silva JM, Camara AA, Tobias KR, Macedo IS, Cardoso MR, Arruda E, et al. A prospective study of wheezing in young children: the independent effects of cockroach exposure, breast-feeding and allergic sensitization. *Pediatr Allergy Immunol* 2005;16:393–401. [PubMed: 16101931]
55. Ramsey CD, Celedon JC, Sredl DL, Weiss ST, Cloutier MM. Predictors of disease severity in children with asthma in Hartford, Connecticut. *Pediatr Pulmonol* 2005;39:268–275. [PubMed: 15668933]
56. Phipatanakul W, Celedon JC, Sredl DL, Weiss ST, Gold DR. Mouse exposure and wheeze in the first year of life. *Ann Allergy Asthma Immunol* 2005;94:593–599. [PubMed: 15948302]
57. Phipatanakul W, Celedon JC, Hoffman EB, Abdulkarim H, Ryan LM, Gold DR. Mouse allergen exposure, wheeze and atopy in the first seven years of life. *Allergy* 2008;63:1512–1518. [PubMed: 18616677]
58. Donohue KM, Al-alem U, Perzanowski MS, Chew GL, Johnson A, Divjan A, et al. Anti-cockroach and anti-mouse IgE are associated with early wheeze and atopy in an inner-city birth cohort. *J Allergy Clin Immunol* 2008;122:914–920. [PubMed: 19000580]
59. Phipatanakul W, Litonjua AA, Platts-Mills TA, Naccara LM, Celedon JC, Abdulkarim H, et al. Sensitization to mouse allergen and asthma and asthma morbidity among women in Boston. *J Allergy Clin Immunol* 2007;120:954–956. [PubMed: 17590423]
60. Chaudhuri N. Interventions to improve children's health by improving the housing environment. *Rev Environ Health* 2004;19:197–222. [PubMed: 15742671]
61. Katial RK. Cockroach allergy. *Immunol Allergy Clin North Am* 2003;23:483–499. [PubMed: 14524387]
62. Eggleston PA. Methods and effectiveness of indoor environmental control. *Ann Allergy Asthma Immunol* 2001;87:44–47. [PubMed: 11770683]
63. Phipatanakul W, Cronin B, Wood RA, Eggleston PA, Shih MC, Song L, et al. Effect of environmental intervention on mouse allergen levels in homes of inner-city Boston children with asthma. *Ann Allergy Asthma Immunol* 2004;92:420–425. [PubMed: 15104193]
64. Slager RE, Poole JA, LeVan TD, Sandler DP, Alavanja MC, Hoppin JA. Rhinitis associated with pesticide exposure among commercial pesticide applicators in the Agricultural Health Study. *Occup Environ Med* 2009;66:718–724. [PubMed: 19289390]
65. Hoppin JA, Umbach DM, London SJ, Henneberger PK, Kullman GJ, Coble J, et al. Pesticide use and adult-onset asthma among male farmers in the Agricultural Health Study. *Eur Respir J* 2009;34:1296–1303. [PubMed: 19541724]
66. Hoppin JA, Umbach DM, London SJ, Henneberger PK, Kullman GJ, Alavanja MC, et al. Pesticides and atopic and nonatopic asthma among farm women in the Agricultural Health Study. *Am J Respir Crit Care Med* 2008;177:11–18. [PubMed: 17932376]
67. Peiris-John RJ, Ruberu DK, Wickremasinghe AR, van-der-Hoek W. Low-level exposure to organophosphate pesticides leads to restrictive lung dysfunction. *Respir Med* 2005;99:1319–1324. [PubMed: 16102957]
68. McConnell R, Jones C, Milam J, Gonzalez P, Berhane K, Clement L, et al. Cockroach counts and house dust allergen concentrations after professional cockroach control and cleaning. *Ann Allergy Asthma Immunol* 2003;91:546–552. [PubMed: 14700438]
69. Gergen PJ, Mortimer KM, Eggleston PA, Rosenstreich D, Mitchell H, Ownby D, et al. Results of the National Cooperative Inner-City Asthma Study (NCICAS) environmental intervention to reduce cockroach allergen exposure in inner-city homes. *J Allergy Clin Immunol* 1999;103:501–506. [PubMed: 10069886]

70. Arbes SJ Jr, Sever M, Archer J, Long EH, Gore JC, Schal C, et al. Abatement of cockroach allergen (Bla g 1) in low-income, urban housing: A randomized controlled trial. *J Allergy Clin Immunol* 2003;112:339–345. [PubMed: 12897740]
71. Arbes SJ Jr, Sever M, Mehta J, Gore JC, Schal C, Vaughn B, et al. Abatement of cockroach allergens (Bla g 1 and Bla g 2) in low-income, urban housing: month 12 continuation results. *J Allergy Clin Immunol* 2004;113:109–114. [PubMed: 14713915]
72. Wood RA, Eggleston PA, Rand C, Nixon WJ, Kanchanaraks S. Cockroach allergen abatement with extermination and sodium hypochlorite cleaning in inner-city homes. *Ann Allergy Asthma Immunol* 2001;87:60–64. [PubMed: 11476465]
73. Eggleston PA, Butz A, Rand C, Curtin-Brosnan J, Kanchanaraks S, Swartz L, et al. Home environmental intervention in inner-city asthma: a randomized controlled clinical trial. *Ann Allergy Asthma Immunol* 2005;95:518–524. [PubMed: 16400889]
74. Morgan WJ, Crain EF, Gruchalla RS, O'Connor GT, Kattan M, Evans R 3rd, et al. Results of a home-based environmental intervention among urban children with asthma. *N Engl J Med* 2004;351:1068–1080. [PubMed: 15356304]
75. Sever ML, Arbes SJ Jr, Gore JC, Santangelo RG, Vaughn B, Mitchell H, et al. Cockroach allergen reduction by cockroach control alone in low-income urban homes: a randomized control trial. *J Allergy Clin Immunol* 2007;120:849–855. [PubMed: 17825893]
76. Phipatanakul W, Cronin B, Wood RA, Eggleston PA, Shih MC, Song L, et al. Effect of environmental intervention on mouse allergen levels in homes of inner-city Boston children with asthma. *Ann Allergy Asthma Immunol* 2004;92:420–425. [PubMed: 15104193]
77. Kattan M, Stearns SC, Crain EF, Stout JW, Gergen PJ, Evans R 3rd, et al. Cost-effectiveness of a home-based environmental intervention for inner-city children with asthma. *J Allergy Clin Immunol* 2005;116:1058–1063. [PubMed: 16275376]

TABLE I**Techniques for allergen reduction (insect and rodent pests)**

Environmental (indoor and outdoor)
<ul style="list-style-type: none">• Remove attractants• Landscaping and vegetation management (prune trees and ornamentals)• Ventilation, temperature, and moisture control• Trash removal and well-placed dumpster site Sanitary• General housekeeping• Detailed cleaning• Sealing (caulking, metal mesh, expandable spray foams, and gels)• Clutter reduction• Storage practices• Disposal frequency
Nonchemical extermination
<ul style="list-style-type: none">• Traps (eg, sticky, snap, curiosity, and light)• Biological agents and pheromones• Predators and parasites• Vacuuming• Freeze, heat, or steam• Repellants• Ultrasound• Lighting
Chemical extermination
<ul style="list-style-type: none">• Insecticides and rodenticides• Formulations (eg, baits)• Insect growth regulators
Public policy
<ul style="list-style-type: none">• Legal housing codes (development and enforcement)• City housing and environmental commissions• Neighborhood housing coalitions

TABLE II

Successful studies on interventions to decrease mouse or cockroach allergen

Reference	Location	Study design	Mouse or cockroach	No., case/control	Type/technique of reduction	Success	Comments	Effect on asthma
McConnell et al ⁶⁸	Los Angeles	Randomized controlled trial	Cockroach	31/18	<ul style="list-style-type: none"> Professional cleaning with bait traps With and without insecticide 	Yes		NA
Gergen et al ⁶⁹	Multiple cities (NCICAS)	Longitudinal intervention	Cockroach	40	<ul style="list-style-type: none"> Professional cleaning with bait traps and insecticide 	Yes	Reduction in cockroach allergen levels at 6 mo but return to baseline levels at 12 mo after intervention	NA
Arbes et al ^{70,71}	North Carolina	Randomized controlled trial	Cockroach	16/15	<ul style="list-style-type: none"> Professional cleaning with bait traps and insecticide 	Yes		NA
Wood et al ⁷²	Baltimore	Randomized controlled trial	Cockroach	14/3	<ul style="list-style-type: none"> Professional cleaning with bait traps and insecticide Cleaning with sodium hypochlorite 	Yes	Reduction in cockroach allergen levels with IPM but sodium hypochlorite did not provide additional allergen reduction	NA
Eggleston et al ⁷³	Baltimore	Randomized controlled trial	Cockroach	50/50	<ul style="list-style-type: none"> HEPA filters Bait trap extermination 	Yes		<ul style="list-style-type: none"> Reduction in daytime asthma symptoms
Morgan et al ⁷⁴	Multiple cities (ICAS)	Randomized controlled trial	Cockroach	469/468	<ul style="list-style-type: none"> Professional cleaning with bait traps and insecticide HEPA filters 	Yes	Successful results for up to 1 y after monitoring of intervention concluded	<ul style="list-style-type: none"> Reduction in daytime symptoms (wheeze, activity disruption) Reduction in sleep disruption Reduction in school days missed

Reference	Location	Study design	Mouse or cockroach	No., case/ control	Type/technique of reduction	Success	Comments	Effect on asthma
Sever et al ⁷⁵	North Carolina	Randomized Controlled trial	Cockroach	40/20	<ul style="list-style-type: none"> • Pest control performed by professional entomologists • Compared with pest control performed by commercial company 	Yes	Successful reduction persisted for 1 y in professional entomologist group compared with the commercial company group	NA
Pongracic et al ⁷⁹	Multiple cities (IC/AS)	Randomized controlled trial	Mouse	150/155	<ul style="list-style-type: none"> • Bait traps • Cleaning • Hole filling • Vacuuming with HEPA filter 	Yes		<ul style="list-style-type: none"> • Reduction in school days missed • Reduction in sleep disruption • Reduction in caretaker burden
Phipatanakul et al ⁷⁶	Boston	Randomized controlled trial	Mouse	12/6	<ul style="list-style-type: none"> • Bait traps with pesticide • Cleaning • Hole filling • Vacuuming with HEPA filter 	YES		<ul style="list-style-type: none"> • No statistically significant differences in asthma symptoms were detected (note: small sample size)

NA, Not applicable.