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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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. (J Allergy Clin Immunol 2010;125:575-81.)

Key words: *Asthma, allergies, environmental allergens, indoor allergens, pest, rodents, inner city, abatement, mouse, cockroach*

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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

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 NCICAS 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 allergen[7] and 56.6% of homes in New Orleans with high levels of cockroach allergen.[8]

Subsequently, Phipatanakul et al[9] 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 al[11] reported 42% of homes in Boston with detectable mouse allergen, and Matsui et al[12] 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 al[14] 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 al[15] 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 al[16] 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 al[17] 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 al[21] 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 al[22] 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 al[35] 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 Brown[39] 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 al[40] 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 al[42] 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 al[45] 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 Kang[47] demonstrated that inhalation of cockroach extract caused a significant decrease in lung function for asthmatic subjects with cockroach allergy. Rosenstreich et al[6] 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 μg/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 wheezing[54] 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 life[56] 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 al[59] 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.

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

Environmental (indoor and outdoor)
• 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
• Traps (eg, sticky, snap, curiosity, and light)
• Biological agents and pheromones
• Predators and parasites
• Vacuuming
• Freeze, heat, or steam
• Repellants
• Ultrasound
• Lighting
Chemical extermination
• Insecticides and rodenticides
• Formulations (eg, baits)
• Insect growth regulators
Public policy
• Legal housing codes (development and enforcement)
• City housing and environmental commissions
• Neighborhood housing coalitions

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

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	• Professional cleaning with bait traps • With and without insecticide	Yes		NA
Gergen et al[69]	Multiple cities (NCICAS)	Longitudinal intervention	Cockroach	40	• 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	• Professional cleaning with bait traps and insecticide	Yes		NA
Wood et al[72]	Baltimore	Randomized controlled trial	Cockroach	14/3	• 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	• HEPA filters • Bait trap extermination	Yes		• Reduction in daytime asthma symptoms
Morgan et al[74]	Multiple cities (ICAS)	Randomized controlled trial	Cockroach	469/468	• Professional cleaning with bait traps and insecticide • HEPA filters	Yes	Successful results for up to 1 y after monitoring of intervention concluded	• Reduction in daytime symptoms (wheeze, activity disruption) • Reduction in sleep disruption • Reduction in school days missed
Sever et al[75]	North Carolina	Randomized Controlled trial	Cockroach	40/20	• 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[49]	Multiple cities (ICAS)	Randomized controlled trial	Mouse	150/155	• Bait traps • Cleaning • Hole filling • Vacuuming with HEPA filter	Yes		• Reduction in school days missed • Reduction in sleep disruption • Reduction in caretaker burden

(Continued)

TABLE II. *(Continued)*

Reference	Location	Study design	Mouse or cockroach	No., case/ control	Type/technique of reduction	Success	Comments	Effect on asthma
Phipatanakul et al[76]	Boston	Randomized controlled trial	Mouse	12/6	• Bait traps with pesticide • Cleaning • Hole filling • Vacuuming with HEPA filter	Yes		• No statistically significant differences in asthma symptoms were detected (note: small sample size)

NA, Not applicable.

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 al[68] 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 al[73] 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 al[75] 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 al[76] 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 al[73] used environmental interventions to reduce cockroach allergen and, subsequently, reduce daytime asthma symptoms.

Most recently, Pongracic et al[49] 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 al[74] 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 al[75] 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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