Exposure to multiple indoor allergens in US homes and its relationship to asthma

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Background: The National Survey of Lead and Allergens in Housing was the first population-based study to measure indoor allergen levels in US homes.

Objective: We characterized the overall burden to multiple allergens and examined whether increased allergen levels were associated with occupants' asthma status.

Methods: This cross-sectional study surveyed a nationally representative sample of 831 housing units in 75 different locations throughout the United States. Information was collected by means of questionnaire and environmental assessment. Allergen concentrations in dust samples were assessed by using immunoassays. The following cutoff points were used to define increased allergen levels: 10 μg/g for Der p 1, Der f 1, and Can f 1; 8 μg/g for Fel d 1; 8 U/g for Bla g 1; 1.6 μg/g for mouse urinary protein; and 7 μg/g for *Alternaria alternata* antigens. Allergen burden was considered high when 4 or more allergens exceeded increased levels in any of the sampling locations.

Results: Exposure to multiple allergens was common in US homes. Of the surveyed homes, 51.5% had at least 6 detectable allergens and 45.8% had at least 3 allergens exceeding increased levels. Race, income, housing type, absence of children, and presence of smokers, pets, cockroaches, rodents, and mold/moisture-related problems were independent predictors of high allergen burden. Among atopic subjects, high allergen burden increased the odds of having asthma symptoms (odds ratio, 1.81; 95% CI, 1.04-3.15).

Conclusion: Increased allergen levels in the home are associated with asthma symptoms in allergic individuals. (J Allergy Clin Immunol 2008;121:678-84.)

Key words: *Allergen, indoor, exposure, asthma, allergy*

Abbreviations used
MUP: Mouse urinary protein (mouse allergen)
NSLAH: National Survey of Lead and Allergens in Housing

Asthma morbidity is a significant public health concern, not only in terms of health care costs but also in terms of lost productivity and reduced quality of life.[1] More than 30 million persons in the United States have been given diagnoses of asthma, and at least two thirds of the patients with diagnosed asthma have current asthma with active symptoms.[2]

Indoor exposures are of great importance in relation to asthma because most persons spend a large amount of their time indoors, especially at home.[3] Exposure to indoor allergens generated from animals, arthropods, rodents, and molds is considered an important risk factor for asthma.[4,5] Although the role of indoor allergen exposure in the development of sensitization and asthma has remained a subject of controversy, there is strong evidence that indoor allergens play a key role in triggering and exacerbating asthma, particularly in sensitized individuals.[6]

In the United States numerous studies of indoor allergens have been conducted; however, many of the studies have focused on single allergens, selected populations (eg, asthmatic, allergic, and inner-city populations), or both.[4,7] Types and levels of allergens have been found to vary substantially by socioeconomic, ethnic, and regional factors among the studied populations, which predominantly represent high-risk groups.[8,9] Yet little information is available about how levels of common indoor allergens vary in the general US population. Although studies suggest that exposure to multiple allergens in homes is not uncommon,[10,11] few studies have examined factors that contribute to high allergen burden across multiple allergens[12] or the role of multiple allergen exposures in relation to asthma.

To characterize and achieve better understanding of the exposure variability in homes, the National Institute of Environmental Health Sciences and the US Department of Housing and Urban Development conducted a survey that assessed levels of several indoor allergens (Bla g 1, Can f 1, Der f 1, Der p 1, Fel d 1, mouse urinary protein [MUP], and *Alternaria alternata*) and endotoxin in the US housing stock. It has been postulated that in addition to allergens, exposure to endotoxin might also influence asthma morbidity.[13] The National Survey of Lead and Allergens in Housing (NSLAH) provides a unique opportunity to examine allergen and endotoxin exposures in relation to asthma in a nationally representative sample of the US population.[14] Our previous publications have described the details of the individual exposures.[13,15-19] In this article we estimate the burden of exposure to multiple allergens in US homes, identify independent predictors of high allergen burden, explore interrelationships between allergen and endotoxin levels, and examine the associations between high allergen burden and asthma-related outcomes among the study population.

METHODS

The data for this cross-sectional study were collected as part of the NSLAH, which used a complex multistage design to sample the US population

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of permanently occupied noninstitutional housing units that permit children. The survey was approved by the National Institute of Environmental Health Sciences Institutional Review Board in 1998. Details of the survey methodology and population characteristics have been previously published.[14] Briefly, a nationally representative sample of 831 housing units inhabited by 2456 individuals within 75 different locations throughout the United States was surveyed. At each home, a residential questionnaire was administered, and environmental data were acquired through inspection and sample collection.

Environmental sampling

Single-surface dust samples were collected from a bed, a sofa, or a chair and from bedroom, living room, and kitchen floors, as previously described.[14] Concentrations of the indoor allergens were measured with immunoassays. Dust mite (Der f 1 and Der p 1), dog (Can f 1), cat (Fel d 1), and cockroach (Bla g 1) allergens were measured by using mAb-based ELISAs.[14] MUP and *A alternata* antigens were assayed with ELISAs by using polyclonal antibodies.[14,18,19] The *A alternata* assay has been shown to measure overall *A alternata* exposure in environmental samples; the polyclonal antibody used is directed against a large range of *A alternata* proteins, including but not limited to known allergens.[20] For most samples, the lower limits of detection were as follows: 0.025 μg/g for Der p 1 and Der f 1; 0.050 μg/g for Can f 1; 0.012 μg/g for Fel d 1; 0.10 U/g for Bla g 1; 0.25 μg/g for MUP; and 0.14 μg/g for *A alternata*. Concentrations less than the lower limits of detection were considered nondetectable. Endotoxin concentrations in the samples were assessed by using the kinetic chromogenic Limulus amebocyte lysate assay with the detection limit of 0.001 EU/mg of sieved dust.[13] The samples that had insufficient amount of dust for the analysis were considered missing. However, allergen measurements were available from at least one room for 99% of the homes. The corresponding percentage for endotoxin was 95%.

Assessment of asthma and allergy

The interviewer-administered questionnaire obtained information on doctor-diagnosed asthma and allergies. Current symptomatic asthma among the subjects with diagnosed asthma was ascertained with a question confirming asthma symptoms in the past year. Atopic status was assessed by report of physician diagnosis of allergies. Although these self-reported health outcomes were assessed and primarily analyzed at the individual level, we also evaluated the outcomes at the household level (ie, household-level definition was based on whether anyone in the household reported the health outcome or none of the residents reported it).

Statistical analysis

All statistical analyses were conducted with SUDAAN software (version 9.1; RTI, Research Triangle Park, NC), and sample weights were applied to all estimates. Details of statistical weighting for the NSLAH have been described elsewhere.[14]

For the purpose of analysis, we dichotomized allergen concentrations using provisional cutoff points that have been associated with asthma morbidity and allergic sensitization.[21-25] Such cutoff points, however, are not as well established for *A alternata* and mouse allergen as they are for other indoor allergens. For mouse allergen, we used a threshold that has been associated with sensitization in recent publications.[18,26] For *A alternata*, we chose a cutoff point that has been associated with increased odds of asthma symptoms in the NSLAH.[27] The cutoff points used in the analysis were as follows: 10 μg/g for Der p 1, Der f 1, and Can f 1; 8 μg/g for Fel d 1; 8 U/g for Bla g 1; 1.6 μg/g for MUP; and 7 μg/g for *A alternata*.

We evaluated the overall burden of exposure to multiple allergens by assessing how many allergens exceeded detection limits and allergen-specific thresholds for increased levels in each home. The allergen-specific exposure level in the home was considered increased if the allergen concentration exceeded the cutoff point in any of the sampling locations. Exposure to dust mite allergens was defined as increased if either Der f 1 or Der p 1 concentrations exceeded 10 μg/g in any of the sampling locations. Exposure to multiple allergens in the home was dichotomized to reflect high (≥4 allergens exceeding increased levels) versus low-medium levels (0-3 allergens exceeding increased levels).

To identify factors that predicted a high burden of exposure to multiple allergens, we performed logistic regression analysis. All potential sociodemographic and housing-related variables were first evaluated by using bivariate analyses. Of the evaluated variables, we selected those with *P* values of less than or equal to .25 (race, income/poverty level, census region, housing type, building year, use of air conditioning/dehumidifier, cleaning frequency, presence of children, smokers, pets, cockroaches, rodents, or mold/moisture-related problems) for inclusion in the regression analysis. In our data-driven modeling approach, we used backward elimination for model selection; starting from the full model, variables with the highest *P* value (Wald F test) were dropped until all remaining predictors in the model had *P* values less than or equal to .05.

For descriptive purposes, we explored exposure patterns in the allergen data. We used logistic regression analysis to determine which allergens cluster together in high levels. To evaluate associations between pairs of allergens, we calculated odds ratios (ORs) with 95% CIs for each pair using dichotomized allergen levels (increased level: yes vs no). Because exposure to endotoxin has been associated with asthma morbidity,[13] we not only looked at interrelationships between different allergens but also at associations between allergen and endotoxin levels. To further characterize the relationship between allergen burden and endotoxin levels, we estimated mean (geometric) endotoxin concentrations for each level of allergen burden. Comparisons of the means were assessed with ANOVA using Wald F statistics.

We compared the allergen burden between asthmatic and nonasthmatic households by using χ^2 statistics. To examine whether high allergen burden was associated with occupants' asthma status at the individual level, we calculated ORs with 95% CIs for the asthma-related outcomes by using logistic regression. The models we present here are adjusted for age, sex, race, education, smoking, season, and endotoxin levels. Because we did not have information on personal smoking, smoking exposure was assessed at the household level (indoor smoking in the home). Although total amount of dust can influence inhaled exposure levels, we did not adjust for dust weight because the adjustment did not appreciably change the ORs (change <5%). We present separate ORs for atopic and nonatopic individuals; the observed effect was modified by atopic status. Subjects with missing data on the exposures were excluded from the analyses at the individual level, leaving 1953 (80%) of 2456 subjects for the analysis.

RESULTS

Distributions of allergen levels

Table I shows percentages of US households with detectable and increased levels of measured allergens. *A alternata*, cat (Fel d 1), and dog (Can f 1) allergens were the most commonly detected allergens; virtually all homes (>99%) had detectable levels in at least 1 sampling location. Detectable levels of dust mite allergens (Der f 1 and Der p 1) were found in at least 85% of the surveyed homes, and mouse (MUP) and cockroach (Bla g 1) allergens were detected in 82% and 63% of the households, respectively. Of the dust mite allergens, Der f 1 had highest levels in bedrooms; *A alternata*, cat, and dog allergens were found to be highest in living rooms; and mouse and cockroach allergen levels tended to be most increased in kitchens (Table I). More detailed information on the distributions can be found elsewhere.[15-19]

Overall burden of multiple indoor allergens

Exposure to multiple allergens in US homes was common (Fig 1). More than half of the homes (51.5%) had detectable levels of all measured allergens. At least 2 allergens were detected in every home (Fig 1, *A*). In less than 8% of the homes, allergen levels did