National prevalence and exposure risk for mouse allergen in US households

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Background: Exposure to mouse allergen is a known cause of asthma in occupational settings and exhibits high prevalence and association with allergic sensitization in inner-city home environments. It has never been characterized on a nationally representative scale.
Objective: This study was designed to characterize mouse allergen prevalence in a representative sample of US homes and to assess risk factors for increased concentrations.
Methods: Allergen, questionnaire, and observational data were analyzed from the first National Survey of Lead and Allergens in Housing, a cross-sectional survey of 831 US housing units. Allergen levels were characterized and related to demographic factors and household characteristics.
Results: Detectable levels of mouse allergen (Mus m 1) exist in 82% of US homes. Kitchen floor concentrations exceed 1.6 μg/g, a level associated with increased sensitization rates, in 22% of homes. Increased concentrations (>1.6 μg/g) were observed in high-rise apartments and mobile homes, older homes, and low-income homes. Odds of having increased concentrations were increased when rodent (odds ratio [OR], 3.38) or cockroach (OR, 1.81) problems were reported and when floor mopping (OR, 2.17) was performed instead of vacuuming.
Conclusions: Household mouse allergen is widespread in many settings at levels that might contribute to asthma morbidity. The likelihood of exposure can be assessed by consideration of demographic and household determinants. (J Allergy Clin Immunol 2004;113:1167-71.)

Key words: *Asthma, allergens, mouse allergen, Mus m 1*

Exposure to rodent allergens and associations with asthma or allergic diseases have been characterized with increasing clarity through focused observational studies of specific populations.[1-8] Mouse allergen in particular has been frequently studied in occupational settings to investigate exposure and response among laboratory animal handlers.[9-13] More recent research has examined home environments, revealing potentially important relationships between household mouse allergen exposure and sensitization among children.[14,15]

Abbreviations used
NCICAS: National Cooperative Inner-City Asthma Study
NIEHS: National Institute of Environmental Health Sciences
NSLAH I: The first National Survey of Lead and Allergens in Housing

A major study targeting the homes of children with asthma living in several inner-city areas found a strikingly high prevalence of mouse allergen and increased mouse allergen sensitization rates.[15] However, in the same study wide variation was observed in kitchen mouse allergen levels between different cities.[14] In particular, about a 25-fold difference was seen between cities having the lowest and highest median concentrations. This strong geographic variation and the narrowly focused population of study are suggestive of possible limitations regarding the scope and applicability of these results on a broader scale.

Nationally representative data are needed to provide a broadly applicable characterization of household mouse allergen levels and their determinants. In this article, such data are taken from the first National Survey of Lead and Allergens in Housing (NSLAH I), which was conducted from 1998 to 1999 by the National Institute of Environmental Health Sciences (NIEHS) and the US Department of Housing and Urban Development. The objectives of this article are to provide the first nationally representative estimates of mouse allergen prevalence at multiple locations within households and to identify demographic factors and housing characteristics associated with high mouse allergen levels. Through those objectives, the larger goals are to characterize household mouse allergen exposure nationwide, to assist clinicians in assessing the likelihood of a patient's exposure, and to generate further research hypotheses for intervention studies.

METHODS

NSLAH I was a cross-sectional survey of the US population of 96 million permanently occupied, noninstitutional housing units that permit resident children and was carried out from 1998 through 1999. A complex and multistage design was used to sample and gain participation from 831 housing units containing 2456 individuals in a total of 75 locations across the United States. At each home, a questionnaire was administered to an adult householder, environmental samples were collected, and observations were recorded. A detailed description of the survey design, methodology, and response rates can be found elsewhere.[16,17] The survey was approved by the

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TABLE I. Estimated distribution of mouse allergen concentration and load in US homes

Sampling location	No. of homes sampled	Concentration, μg/g		Load, μg/m²	
		Median	Geometric mean	Median	Geometric mean
Bedroom bed	660	0.25	0.32	0.034	0.041
Bedroom floor	729	0.28	0.37	0.061	0.077
Kitchen floor*	735	0.36	0.52	—	—
Living room floor†	694	<LLOD	0.33	0.045	0.058
Living room upholstery*†	656	<LLOD	0.28	—	—

*Vacuumed area not recorded; unit load not calculated.
†Median is less than the lower limit of detection (LLOD).

TABLE II. Estimated percentage of US households with detectable kitchen floor mouse allergen concentrations, levels exceeding 1.60 μg/g, and the geometric mean concentration, according to demographic factors

Factor	No. of homes sampled	Percent detectable (SE)	Percent >1.60 μg/g (SE)	Geometric mean (SE), μg/g
Total	735	57.0 (2.1)	21.7 (2.1)	0.52 (0.04)
Type of dwelling (P = .009)*				
Detached single family	487	57.2 (2.7)	18.8 (2.6)	0.48 (0.04)
Duplex-triplex	48	67.7 (7.8)	37.4 (6.8)	0.80 (0.21)
Row house	36	50.3 (11.9)	23.7 (6.8)	0.55 (0.19)
Low-rise apartment (1-4 floors)	74	40.7 (8.1)	16.1 (4.3)	0.37 (0.07)
High-rise apartment (≥5 floors)	15	81.5 (10.3)	34.6 (15.6)	1.98 (1.44)
Mobile home	38	80.0 (7.4)	40.8 (13.3)	1.08 (0.38)
Construction year (P = .003)				
1978-1998	194	50.4 (4.8)	21.2 (3.8)	0.45 (0.06)
1960-1977	227	53.3 (4.8)	18.3 (2.9)	0.43 (0.04)
1946-1959	123	55.8 (4.8)	23.2 (4.5)	0.53 (0.09)
1940-1945	42	72.7 (9.7)	21.1 (6.5)	0.71 (0.20)
1939 or earlier	149	69.0 (3.1)	26.5 (4.0)	0.73 (0.07)
Geographic region (P = .642)				
Northeast	130	55.1 (4.7)	18.4 (2.7)	0.46 (0.05)
Midwest	178	56.6 (4.1)	21.5 (2.1)	0.55 (0.06)
South	256	57.1 (4.1)	23.4 (4.5)	0.48 (0.08)
West	171	59.2 (3.5)	21.7 (5.2)	0.59 (0.12)
Urbanization (P = .742)				
MSA ≥1 million population	245	57.4 (3.3)	20.1 (2.2)	0.56 (0.05)
MSA <1 million population	362	53.2 (3.2)	20.9 (4.0)	0.48 (0.07)
Non-MSA	128	63.9 (4.1)	25.0 (2.1)	0.54 (0.06)
Household income (P = .008)				
$0-$19,999	166	66.9 (4.0)	32.9 (4.6)	0.81 (0.15)
$20,000-$39,999	199	57.3 (4.9)	23.6 (3.6)	0.54 (0.08)
$40,000-$59,999	141	55.2 (5.6)	14.5 (3.8)	0.39 (0.04)
≥$60,000	174	47.2 (4.8)	17.0 (3.1)	0.42 (0.06)
Child resident (P = .779)				
Child resident <18 y old	354	52.9 (3.8)	21.1 (2.9)	0.50 (0.05)
No child resident	378	59.6 (2.3)	22.2 (2.3)	0.52 (0.04)

MSA, Metropolitan statistical area.
*Wald F test for equality of geometric means among all levels of the factor.

NIEHS Institutional Review Board on June 16, 1998, and in each home, informed consent was obtained in writing from an adult household member.

Sample collection

Dust samples used in this analysis were collected from the kitchen floor, living room floor, upholstered living room furniture, a randomly selected bedroom bed, and bedroom floor by using a Eureka Mighty-Mite 7.0-A vacuum cleaner (Eureka Co). A 19 mm × 90 mm cellulose extraction thimble (Whatman International, Ltd) was placed in the distal end of the vacuum's extension tube, sealed with a rubber o-ring, and covered with a clean crevice tool. Details of dust collection protocols are described elsewhere.[16]

At the laboratory, dust samples were sieved through 425-μm pore grating, weighed, and divided into 100-mg aliquots of fine dust. Dust aliquots were extracted in borate-buffered saline and clarified by means of centrifugation. Supernatants were decanted and stored at −20°C. Allergen concentrations were measured according to previously published methods.[16,18,19] Allergen concentrations reported in this article are of Mus m 1, or mouse urinary protein,

TABLE III. Estimated percentage of US households with kitchen floor mouse allergen concentrations exceeding 1.60 μg/g, by construction year and type of dwelling

Type of dwelling	No. of homes sampled	Percent >1.60 μg/g (SE)	
		Constructed 1960-1998	Constructed 1959 or earlier
Detached single family	487	16.2 (3.0)	22.3 (3.3)
Duplex-triplex	48	44.5 (12.9)	32.2 (11.0)
Row house	36	17.8 (9.3)	30.4 (10.3)
Low-rise apartment (1-4 floors)	74	13.1 (5.2)	22.3 (6.8)
High-rise apartment (≥5 floors)	15	10.2 (10.2)	50.2 (20.6)
		Constructed 1978-1998	Constructed 1960-1977
Mobile home	37	51.7 (15.8)	22.5 (13.2)

measured in micrograms of allergen per gram of sampled dust. For most samples, the lower limit of detection of the assay was 0.25 μg/g. Allergen loads are calculated as the product of concentration and dust weight measured in micrograms of allergen per square meter of sampled area. Because some dust samples were not collected and because some samples had too little dust to analyze for all allergens, there were some missing concentration values.

Statistical analyses

Spearman rank correlation coefficients were calculated as a robust measure of association between allergen concentrations. Odds ratios (ORs) and 95% CIs were estimated by using logistic regression and Wald F test statistics. Factors were selected for modeling on the basis of hypothesized relevance gleaned from the literature or other sources. All percentages, correlations, means, percentiles, and ORs were weighted to represent the US population of permanently occupied, noninstitutional housing units that permit resident children. SEs, CIs, and *P* values were developed in accordance with the complex survey design by using Taylor series linearization methods. Statistical analyses were conducted in SUDAAN, Release 8.0 (Research Triangle Institute) and S-Plus (version 6, Release 2). A detailed description of the statistical weighting for the NSLAH I can be found elsewhere.[16]

RESULTS

The weighted NSLAH population is, by design, comparable with the US population of permanently occupied, noninstitutional housing units that permit resident children: 28% in urban areas with populations of greater than 1 million, 39% with children less than 18 years of age, 80% white, 8% Hispanic, and 80% above the poverty level.

Distributions of allergen concentrations

Detectable concentrations of mouse allergen were found in at least one sampling location of an estimated 82% of US homes. Kitchen floors exhibited the highest prevalence, with 57% exceeding the lower limit of detection and with 22% having concentrations of greater than 1.6 μg/g, a level previously found to be associated with significantly increased mouse allergen sensitization rates. Table I shows the median (50th percentile) and geometric mean of mouse allergen concentration and load in US homes.

Spearman rank correlations of mouse allergen concentrations between the sampling locations ranged from 0.17 (bedroom bed and kitchen floor) to 0.43 (living room floor and living room upholstery). All correlations among the 3 floor surfaces (kitchen, bedroom, and living room) were between 0.29 and 0.31.

Among other measured allergen concentrations, mouse was most highly correlated with *Alternaria* species (Alt a 1) in a range of 0.22 to 0.38 across the sampling locations and cockroach (Bla g 1) in a range of 0.14 to 0.25.

TABLE IV. Adjusted* ORs (95% CIs) for increased kitchen floor mouse allergen concentration, according to household characteristics

Characteristic	OR for higher Mus m 1 when characteristic is present	
	Mus m 1 >0.52 μg/g	Mus m 1 >1.60 μg/g
Reported problems with rodents	3.31 (1.82-6.01)	3.38 (1.94-5.89)
Rodents in room†	3.27 (1.02-10.48)	2.95 (0.83-10.48)
Reported problems with cockroaches	1.64 (1.04-2.59)	1.81 (1.04-3.15)
Live-dead cockroaches in room†	1.58 (0.88-2.85)	2.30 (1.20-4.43)
Work with animals	1.00 (0.41-2.45)	1.82 (0.67-4.97)
Floor mopped (vs vacuumed) when last cleaned	1.67 (0.98-2.87)	2.17 (1.20-3.93)
Floor swept (vs vacuumed) when last cleaned	1.23 (0.66-2.31)	1.29 (0.57-2.94)
Floor carpeted†	0.93 (0.55-1.57)	0.85 (0.38-1.93)
Cockroach stains in room†	1.12 (0.59-2.11)	1.82 (0.86-3.84)
Food debris in room†	1.06 (0.67-1.68)	1.00 (0.58-1.73)

*Adjusted for type of dwelling, construction year, and household income.
†On the basis of in-home observation.

Mouse allergen and household characteristics

To investigate associations between mouse allergen and various demographic factors, we tested the equality of the geometric mean kitchen floor concentration across levels of the factors shown in Table II. Kitchen floor concentrations were used because they were previously found to exhibit the strongest relationship to sensitization relative to a threshold of 1.60 μg/g.[15] Generally higher concentrations were observed in high-rise apartments, mobile homes, and duplex-triplex residences, with the lowest concentrations in low-rise apartments. Stated in terms of risk, ORs for elevated (>1.60 μg/g) concentrations were 2.28 for high-rise apartments and 2.98

TABLE V. Results from a low-income urban subpopulation of NSLAH I compared with NCICAS subpopulation and to all US homes

Result	Population		
	Low-income homes of children with diagnosed asthma, selected US cities (from NCICAS)	Low-income urban US homes (from NSLAH I)	All US homes (from NSLAH I)
Percent of homes with detectable Mus m 1 in at least one room	95%	95%	82%
Percent of kitchens with detectable Mus m 1	87%	83%	57%
Percent of kitchens with Mus m 1 exceeding 1.6 μg/g	50%	33%	22%
Range of rank correlations of Mus m 1 among 3 rooms*	0.65-0.75	0.32-0.81	0.17-0.43

*NSLAH I subpopulation living room and bedroom Mus m 1 was defined as the weighted average concentration across sampled sites from each room, for comparability with NCICAS.

for mobile homes, each as compared with detached single-family homes. Concentrations consistently increased with increasing age of the home and with decreasing household income. Only slight differences were observed according to geographic region of the country, degree of urbanization, and presence of a child in the home.

Table III provides a more detailed view of the relationship between allergen level and construction year for each dwelling type. Most dwelling types reflected the overall pattern of increasing concentrations with age of the home. Exceptions were duplex-triplex and mobile homes. For this analysis, limited numbers of homes in several subcategories necessitated collapsing across construction-year ranges and defining different construction-year groupings for mobile homes.

After accounting for demographic factors, specific household characteristics were analyzed to investigate their ability to predict higher levels of kitchen floor mouse allergen relative to 2 thresholds: 0.52 μg/g (the estimated national geometric mean) and 1.60 μg/g. Results are displayed in Table IV. Higher mouse allergen levels were observed in the presence of characteristics associated with rodent or cockroach activity. Floor mopping was also associated with higher levels compared with vacuuming.

Comparability with National Cooperative Inner-City Asthma Study results

NSLAH I data were used to define a subpopulation, restricted to households in low-income urban neighborhoods, to facilitate comparison against selected results from the National Cooperative Inner-City Asthma Study (NCICAS)[14] strictly for mutual validation purposes. The subpopulations are not identical, primarily because the NSLAH I sample size prevents further reduction to only include households of children with diagnosed asthma; however, the demographic-based restriction alone was deemed sufficient to support a general comparison (Table V).

Prevalence of detectable mouse allergen was comparable and, in some respects, identical between the 2 subpopulations. Both studies found that 95% of low-income urban homes had detectable mouse allergen in at least one room and that 83% to 87% had detectable levels in the kitchen. The prevalence of increased kitchen concentrations and the correlation of concentrations between rooms differed somewhat between the 2 studies, but these were not incongruent in view of the high variability seen across NCICAS cities.

DISCUSSION

This article provides the first nationally representative estimates of household mouse allergen prevalence and finds that prevalence of mouse allergen is widespread, with detectable levels in 82% of all homes, which is less but not dramatically lower than the 95% prevalence in inner-city homes alone, as found in this and other studies.[14] This study also finds that 22% of US kitchen floors exhibit elevated concentrations relative to the previously established 1.6 μg/g threshold, as related to allergic sensitization.[15] These results provide an important perspective on the breadth of health effects potentially associated with exposure to mouse allergen. Although perhaps greater in low-income urban environments, the allergen is widespread, and elevated levels are not restricted to those environments.

Elevated mouse allergen levels are most prevalent in pre-1945 construction, households with incomes of less than $20,000, and high-rise apartments, mobile homes, and duplex-triplex residences. Apart from these factors, levels of mouse allergen do not vary appreciably across large geographic quadrants, urban versus rural settings, or households with and without resident children.

After accounting for the demographics, elevated exposure risk is most strongly associated with the reported or observed presence of rodents or cockroaches, as expected. ORs for these factors range between 1.58 and 3.38. Also, kitchen floor mopping, as opposed to vacuuming, carries a marginal increase in risk of exposure. This was not found in some prior research and provides

added context to what is known about disturbance and activity levels increasing airborne allergen exposure.[19,20] Type of flooring and presence of food debris are not associated with elevated risk for kitchen floor allergen levels; however, in other (nonkitchen) rooms, allergen levels and food debris did exhibit such associations. For example, food debris observed in the living room is associated with elevated living room upholstery mouse allergen levels (OR, 2.61; 95% CI, 1.85-3.67). Our results also suggest that working with animals does not necessarily translate into elevated mouse allergen levels in the home; however, our question on occupational exposure did not differentiate types of animal work, and a more specific question on mouse-related occupations might have illuminated a real association relative to the 1.6 μg/g threshold.

On the basis of a completely data-driven prediction model generated through consideration of all factors and backward elimination model fitting (not shown), essentially these same factors were found to constitute independent predictors of increased mouse allergen concentration: dwelling type, construction year, household income, reported problems with rodents, reported problems with cockroaches, and floor-cleaning method.

Allergen levels vary within the home but correlate significantly between rooms and between floored and upholstered surfaces within a room. This finding is consistent with research on airborne allergens in occupational settings, which suggested small-particle transportation of the allergen into rooms without mice, in some cases over substantial distances.[21] Thus direct contact is not a necessary condition for exposure, but avoidance of areas in which mice are present should reduce risk.[22-24]

This study, which is demonstrably consistent with prior research while extending the scope and mitigating the inherent variability thereof, indicates widespread prevalence of mouse allergen in homes and demonstrates where the risk is greatest. These results might help clinicians to assess whether a patient is likely to be exposed and suggest measures to reduce this exposure. Our results further suggest the need for additional investigation in longitudinal studies of mouse allergen in relation to health outcomes.

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