Dog allergen (Can f 1) and cat allergen (Fel d 1) in US homes: Results from the National Survey of Lead and Allergens in Housing

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Background: Exposures to dog and cat allergens are believed to play important roles in the etiology of asthma; however, the levels of these allergens have never been assessed in a representative sample of US homes.

Objective: The objective of this study was to estimate and characterize exposures to Can f 1 (dog allergen) and Fel d 1 (cat allergen) in US homes.

Methods: Data were obtained from the National Survey of Lead and Allergens in Housing, a nationally representative survey of 831 US homes. Vacuumed-collected dust samples from the bed, bedroom floor, living room floor, and living room sofa were analyzed for concentrations of Can f 1 and Fel d 1 (micrograms of allergen per gram of dust).

Results: Although a dog or cat had lived in only 49.1% of homes in the previous 6 months, Can f 1 and Fel d 1 were detected in 100% and 99.9% of homes, respectively. Averaged over the sampled sites, geometric mean concentrations (μg/g) were 4.69 for Can f 1 and 4.73 for Fel d 1. Among homes with an indoor dog and cat, respectively, geometric mean concentrations were 69 for Can f 1 and 200 for Fel d 1. Among homes without the indoor pet, geometric mean concentrations were above 1.0. The independent predictors of elevated concentrations in homes without pets were all demographic variables that were also linked to a higher prevalence of pet ownership.

Conclusions: Can f 1 and Fel d 1 are universally present in US homes. Levels that have been associated with an increased risk of allergic sensitization were found even in homes without pets. Because of the transportability of these allergens on clothing, elevated levels in homes without pets, particularly among demographic groups in which pet ownership is more prevalent, implicate the community as an important source of these pet allergens. (J Allergy Clin Immunol 2004;114:111-7.)

Key words: *Allergens, asthma, cat allergen, Can f 1, dog allergen, epidemiology, Fel d 1, survey*

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Abbreviations used

NIEHS: National Institute of Environmental Health Sciences

NSLAH: National Survey of Lead and Allergens in Housing

Asthma is a chronic respiratory disease characterized by episodes of airway inflammation and narrowing. Although it is not fully understood why some people develop asthma and others do not, it is generally accepted that asthma is the result of the interaction between genetic susceptibility and environmental exposures, such as exposures to indoor allergens. Numerous studies have shown that asthmatics are more likely than nonasthmatics to be sensitized to one or more indoor allergens.[1-10] However, little is known about the extent of indoor allergen exposures across the US housing stock.

From 1998 to 1999, the National Institute of Environmental Health Sciences (NIEHS) and the US Department of Housing and Urban Development conducted the National Survey of Lead and Allergens in Housing (NSLAH). The primary objective of the allergen component was to provide nationwide estimates of exposure to 7 indoor allergens and to identify housing characteristics that predict allergen levels. Results for 2 of the allergens (dust mite and mouse) have been published.[11,12] This article reports on the levels of dog and cat allergens in US homes and the household characteristics associated with these allergens.

METHODS

Study data

Data were obtained from the NSLAH, a cross-sectional survey that used a complex, multistage design to sample the US population of permanently occupied, noninstitutional housing units that permit resident children. The demographic and housing characteristics of the weighted NSLAH sample were comparable to the characteristics reported for other national housing surveys.[13] The survey methodology, along with a complete discussion of its representativeness and response rate, is described elsewhere.[13,14] In all, 831 housing units containing 2456 individuals were surveyed in 75 locations across the United States. Information on housing and household characteristics was determined by questionnaire or observation. The

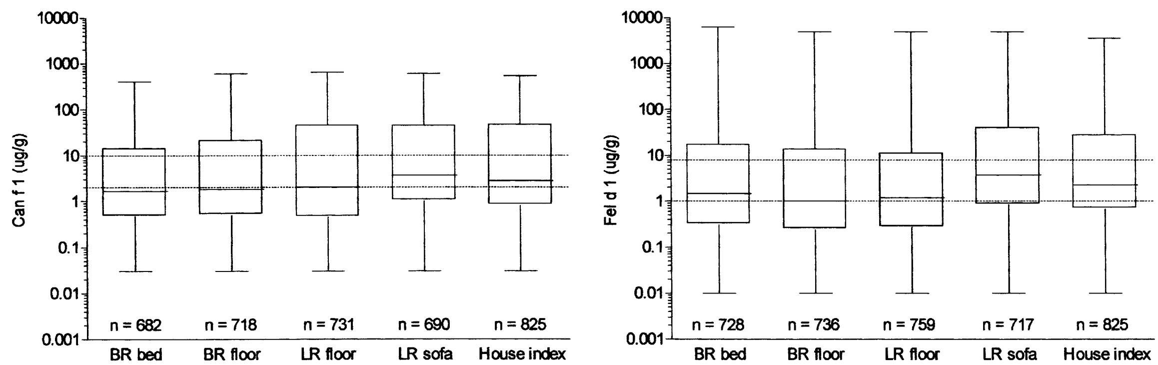

FIG 1. Distributions of Can f 1 and Fel d 1 concentrations in US homes. *Box plots* represent the 0, 25th, 50th, 75th, and 100th percentiles. The house index is the mean of the sample location concentrations. The *dotted lines* represent the proposed thresholds of exposure that have been associated with an increased risk of sensitization (>2 ug/g for Can f 1 and >1 ug/g for Fel d 1) and asthma symptoms in allergic patients (>10 ug/g for Can f 1 and >8 ug/g for Fel d 1).

survey was approved by the NIEHS Institutional Review Board on 16 June 1998.

Assessment of allergens

In each home, vacuumed dust samples were collected from one bed, the floor in the same bedroom, the living room floor, and the living room sofa (or other upholstered furniture). In the laboratory, dust samples were analyzed for Can f 1 and Fel d 1 using monoclonal antibody enzyme-linked immunosorbent assays.[15,16] Details of the vacuum sampling and the laboratory procedures were previously published.[13] For most samples, the lower level of detection was 0.050 µg of allergen per gram of vacuumed dust for the Can f 1 assays and 0.012 µg/g for the Fel d 1 assays. For statistical analyses, samples below the level of detection were assigned one-half the lower level of detection. Because some samples had too little dust to analyze for all allergens, there were missing Can f 1 and Fel d 1 values (see Fig 1). An allergen-specific house index was created that is the mean of the sample location concentrations.

Statistical analyses

Bivariate associations between categorical variables were assessed with χ^2 statistics. Mean differences in $\log_{10}$-transformed allergen concentrations between sample locations were assessed with paired *t* tests. Bivariate associations between housing characteristics and the means of the $\log_{10}$-transformed house indices were assessed with univariate linear regression. Independent predictors of allergen concentrations were identified with multivariable linear regression modeling using a backward elimination procedure, starting with variables in Table 1 with $P \leq .200$. All reported beta coefficients, correlations, means, percentages, and percentiles were weighted to represent the US population of permanently occupied, noninstitutional housing units that permit resident children. Standard errors (SE) were adjusted for the complex survey design using Taylor series linearization methods (SUDAAN, Release 8.0.1, Research Triangle Institute, Research Triangle Park, NC). Statistical significance was set at $P \leq .05$.

RESULTS

Dogs and cats in US homes

The majority of households, 54.9% (SE = 2.1), had neither a dog nor a cat living in the home at the time of the survey. Among all homes, 10.4% (1.3) had both pets living in the home, 21.4% (2.0) had at least 1 dog but not a cat living in the home, and 13.4% (1.7) had at least 1 cat but not a dog living in the home. Half of the households (50.9%, SE = 2.5) had not had either pet living in the home in the past 6 months.

Because of the intimate relationships between these indoor pets and indoor levels of their allergens, which will be described later, bivariate associations between housing characteristics and the presence of an indoor dog and cat were examined. The percentage of households with an indoor dog was greater among households living in census regions other than the northeast (33.9 vs 23.1, $P = .039$), in single-family housing rather then multifamily housing (35.5 vs 8.0, $P < .001$), and in owned rather than rented homes (39.5 vs 14.3, $P < .001$). Percentages were also higher for households that had more than 1 member (35.3 vs 15.8, $P = .002$), had an income above $20,000 rather than below (34.9 vs 20.5, $P = .007$), were white rather than black or other races (34.7 vs 21.4, $P = .017$), and were non-Hispanic rather than Hispanic (33.2 vs 19.3, $P = .019$).

The percentage of households with an indoor cat was greater among households that lived in the northeast and west (29.4 and 33.4) rather than the midwest and south (20.9 and 17.2, $P = .001$), were white rather than black or other races (26.7 vs 10.8, $P < .001$), and were non-Hispanic rather than Hispanic (24.4 vs 15.2, $P = .021$).

Distribution of Can f 1 in US homes

Detectable levels of Can f 1 were found in 93.8% (SE = 1.1) of the beds, 95.6% (0.9) of the bedroom floors, 94.9% (0.9) of the living room floors, and 98.0% (0.5) of the living room sofas. Of the 818 homes with data, 817 (99.9%, SE = 0.1) had detectable Can f 1 in at least 1 sample location. As illustrated in Figure 1 *(left panel),* the sofa had the highest median level of Can f 1. The geometric mean concentrations (µg/g) were 2.48 (SE = 0.26) for the bedroom bed, 2.99 (0.34) for the bedroom floor, 3.61 (0.48) for the living room floor, 5.49 (0.62) for the living room sofa, and 4.69 (0.56) for the house index. The sample location geometric means were

TABLE I. Geometric mean concentrations for the Can f 1 and Fel d 1 house indices by demographic and housing characteristics

Characteristic	N	Geometric Mean (SE) Concentration in μg/g			
		Can f 1	***P***	**Fel d 1**	***P***
Total	825	4.69 (0.56)	—	4.73 (0.46)	—
Year home constructed					
1978-1998	219	6.15 (1.52)		5.15 (0.95)	
1977 or earlier	606	4.15 (0.43)	.116	4.55 (0.63)	.635
1990 census region					
Northeast	153	2.92 (0.74)		4.34 (1.15)	
Midwest	195	4.68 (1.20)		5.16 (0.86)	
South	277	5.41 (1.22)		3.19 (0.41)	
West	200	5.82 (1.06)	.158	9.88 (2.26)	.001
Metropolitan Statistical Area (MSA)					
MSA ≥ 1 million	273	3.82 (0.77)		4.34 (0.93)	
MSA < 1 million	414	4.50 (0.83)		5.24 (0.68)	
Not an MSA	138	6.45 (1.49)	.234	4.27 (0.76)	.575
Housing unit type					
Single family	700	5.83 (0.74)		4.90 (0.53)	
Multifamily	125	1.19 (0.25)	<.001	3.78 (1.18)	.452
Owner/renter					
Owner occupied	538	6.68 (1.01)		4.73 (0.58)	
Renter occupied	284	2.10 (0.33)	<.001	4.77 (1.08)	.972
Number of persons in household					
1	124	2.51 (0.60)		5.05 (1.48)	
2	252	5.93 (1.24)		4.29 (0.77)	
3	171	4.37 (0.92)		5.27 (0.98)	
4 or more	278	5.56 (0.89)	.007	4.75 (0.81)	.901
Child < 18 years of age					
Yes	395	4.83 (0.62)		4.83 (0.73)	
No	427	4.61 (0.80)	.825	4.66 (0.62)	.859
Household income					
<$20,000	187	2.54 (0.49)		2.70 (0.60)	
$20,000-39,999	227	3.40 (0.64)		4.03 (0.91)	
$40,000-59,999	150	8.56 (2.24)		7.06 (1.65)	
≥$60,000	202	6.81 (1.30)	<.001	6.83 (1.63)	.007
Race of youngest member					
White	619	6.34 (0.82)		6.51 (0.74)	
Black	115	1.09 (0.28)		0.69 (0.14)	
Other	76	1.86 (0.44)	<.001	2.40 (0.70)	<.001
Youngest member Hispanic					
Yes	85	1.29 (0.32)		1.33 (0.28)	
No	731	5.34 (0.69)	<.001	5.20 (0.52)	<.001
Highest education any member					
Less than high school	82	2.87 (1.04)		3.90 (1.27)	
High school diploma	175	3.96 (0.95)		2.28 (0.63)	
Above high school	554	5.34 (0.69)	.237	6.03 (0.72)	.012
Household poverty level					
At or below	137	2.46 (0.56)		3.12 (0.82)	
Above	645	5.34 (0.65)	.003	5.08 (0.55)	.088
Home's main heating source					
Gas or electric forced air	559	5.47 (0.80)		4.90 (0.63)	
Steam or hot water radiator	75	3.60 (1.33)		4.99 (1.25)	
Other (space heater, etc)	188	3.43 (0.51)	.045	4.00 (0.83)	.686
Air conditioner in the home					
Yes	650	5.19 (0.72)		4.86 (0.57)	
No	174	3.12 (0.48)	.022	4.31 (1.34)	.737
Air filtration device in the home					
Yes	101	3.98 (1.02)		4.00 (1.32)	
No	705	4.92 (0.63)	.437	4.88 (0.52)	.576
Season sampled					
Winter	195	5.52 (1.32)		6.40 (1.50)	

(Table continued on next page)

TABLE I. *(Continued)*

Characteristic	N	Geometric Mean (SE) Concentration in µg/g			
		Can f 1	*P*	Fel d 1	*P*
Summer	285	5.08 (0.91)		4.09 (0.73)	
Fall	345	3.84 (0.71)	.427	4.40 (0.65)	.316
Dog currently living in the home					
Yes	247	69.23 (7.88)		7.33 (1.41)	
No	570	1.33 (0.12)	<.001	3.84 (0.55)	.020
Cat currently living in the home					
Yes	187	9.42 (2.24)		199.70 (31.22)	
No	630	3.78 (0.51)	.001	1.47 (0.09)	<.001

For each allergen, the house index represents the mean of the sample location concentrations.

TABLE II. Final linear regression model for the prediction of the Can f 1 house index (log_{10}-transformed, N = 797, R^2 = .64)

Independent variables	Beta	SE	*P*
Intercept	−0.461	0.088	—
Race			
Black or other	0.000	0.000	
White	0.433	0.061	<.001
Hispanic ethnicity			
Yes	0.000	0.000	
No	0.269	0.097	.008
Indoor dog			
No	0.000	0.000	
Yes	1.663	0.055	<.001

TABLE III. Final linear regression model for the prediction of the Fel d 1 house index (log_{10}-transformed, N = 741, R^2 = .62)

Independent variables	Beta	SE	*P*
Intercept	−0.718	0.188	—
Region			
Northeast	0.000	0.000	
Midwest	0.266	0.089	
South	0.173	0.083	
West	0.354	0.099	.004
Household income ($)			
<$20,000	0.000	0.000	
$20,000-39,999	0.149	0.080	
$40,000-59,999	0.241	0.072	
≥$60,000	0.186	0.085	.005
Race			
Black or other	0.000	0.000	
White	0.358	0.061	<.001
Hispanic ethnicity			
Yes	0.000	0.000	
No	0.292	0.095	.003
Indoor cat			
No	0.000	0.000	
Yes	2.055	0.072	<.001

statistically different from each other. Between any two sample locations, the log_{10}-transformed concentrations were highly correlated, with the lowest Pearson correlation coefficient being .78 ($P < .001$) between the bedroom bed and the living room floor and the highest being 0.88 ($P < .001$) between the living room floor and sofa.

Distribution of Fel d 1 in US homes

Detectable levels of Fel d 1 were found in 96.6% (SE = 0.6) of the beds, 96.9% (0.8) of the bedroom floors, 96.1% (0.8) of the living room floors, and 97.9% (0.5) of the living room sofas. All homes (of the 823 with data) had detectable Fel d 1 in at least 1 sample location. As with Can f 1, the sofa had the highest level of Fel d 1 (Fig 1, *right panel*). The geometric mean concentrations (µg/g) were 2.74 (SE = 0.29) for the bedroom bed, 2.13 (0.23) for the bedroom floor, 2.14 (0.26) for the living room floor, 6.17 (0.68) for the living room sofa, and 4.73 (0.46) for the house index. The sample location geometric means were significantly different from each other with the exception of the 2 floor means. Between any 2 sample locations, the lowest Pearson correlation coefficient was .75 ($P < .001$) between the bedroom bed and the living room floor and the highest was .86 ($P < .001$) between the bedroom bed and floor. Homes with higher Can f 1 levels tended to have higher Fel d 1 levels. The Pearson correlation coefficient comparing the Can f 1 and the Fel d 1 house indices (log_{10}-transformed) was .20 ($P < .001$).

Exposures above clinically relevant thresholds

The dotted lines in Fig 1 represent provisional threshold levels for sensitization and asthma symptoms in sensitized asthmatics.[8,10,17] These thresholds are >2 and >10 µg/g, respectively, for Can f 1 and >1 and >8 ug/g, respectively, for Fel d 1. For the Can f 1 house index, 55.7% (SE = 2.2) of US homes exceeded the sensitization threshold and 34.9% (SE = 2.1) exceeded the asthma symptom threshold. For the Fel d 1 house index, 66.0% (SE = 1.6) of US homes exceeded the sensitization threshold and 34.7% (SE = 1.5) exceeded the asthma symptom threshold.

Predictors of the Can f 1 house index

Table I shows the bivariate associations between housing characteristics and the Can f 1 house index. Geometric mean concentrations of Can f 1 were significantly higher for single-family homes than for

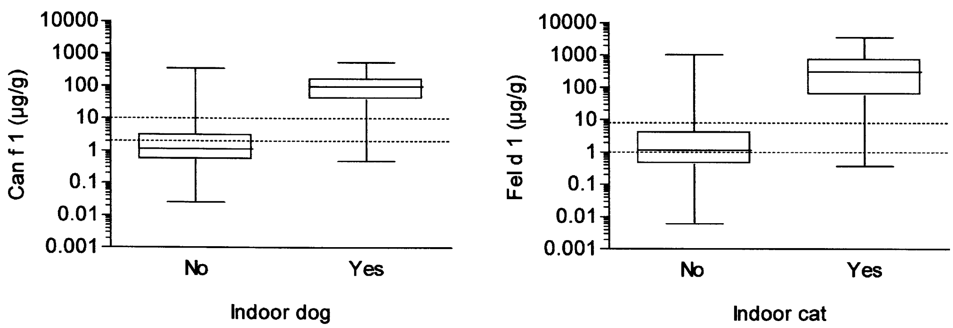

FIG 2. Distributions of Can f 1 and Fel d 1 house indices in US homes with and without a dog or cat living in the home at the time of the survey. *Box plots* represent the 0, 25th, 50th, 75th, and 100th percentiles. The *dotted lines* represent the proposed thresholds of exposure that have been associated with an increased risk of sensitization (>2 µg/g for Can f 1 and >1 µg/g for Fel d 1) and asthma symptoms in allergic patients (>10 µg/g for Can f 1 and >8 µg/g for Fel d 1).

multifamily homes, for owner-occupied homes than for renter-occupied homes, for homes with more than 1 household member, for higher income households, for white households, for non-Hispanic households, for households above the poverty level, for homes with forced-air heating, for homes with air conditioning, for homes with an indoor dog, and for homes with an indoor cat. As one would expect, the presence or absence of an indoor dog had the largest influence on the geometric mean (69.23 vs 1.33 µg/g).

Table II shows the final multivariable prediction model for the Can f 1 house index. Of the variables bivariately associated with the Can f 1 index at $P \leq .200$, the independent predictors were race, Hispanic ethnicity, and a dog living in the home.

Predictors of the Fel d 1 house index

Bivariate associations between the housing characteristics and the Fel d 1 house index are shown in Table I. Fel d 1 geometric mean concentrations were significantly higher for homes in the west census region than in any other region, for households with higher income, for white households, for non-Hispanic households, for households with above high school education, for homes with an indoor dog, and for homes with an indoor cat. The presence or absence of an indoor cat had the largest influence on the geometric mean (199.70 vs 1.47 µg/g).

Table III shows the final multivariable prediction model for the Fel d 1 house index. The independent predictors of the Fel d 1 house index were census region, household income, race, Hispanic ethnicity, and cat living in the home.

Can f 1 and Fel d 1 in homes without pets

In homes without an indoor dog, the geometric mean Can f 1 concentrations (µg/g) were 0.76 (SE = 0.08) for the bedroom bed, 0.86 (0.09) for the bedroom floor, 0.91 (0.10) for the living room floor, 1.65 (0.15) for the living room sofa, and 1.33 (0.12) for the house index. Distributions of the Can f 1 house index in homes with and without an indoor dog are shown in Fig 2 *(left panel),* along with the provisional thresholds for sensitization and asthma symptoms. For Can f 1, 98.0% (SE = 0.8) of homes with an indoor dog and 36.2% (SE = 2.6) of homes without an indoor dog were above the sensitization threshold. Likewise, 89.7% (SE = 2.3) of homes with an indoor dog and 9.3% (SE = 1.7) of homes without an indoor dog were above the asthma symptom threshold. Among the homes without an indoor dog, the final multivariable model for the Can f 1 house index contained the variables race ($P < .001$), Hispanic ethnicity ($P = .014$), and household income ($P = 0.036$).

In homes without an indoor cat, the geometric mean concentrations were 0.80 (SE = 0.07) for the bedroom bed, 0.60 (0.05) for the bedroom floor, 0.68 (0.7) for the living room floor, 2.07 (0.15) for the living room sofa, and 1.47 (0.09) for the house index. Fig 2 *(right panel)* shows the box plots for the Fel d 1 house index in homes with and without an indoor cat, along with the thresholds for sensitization and asthma symptoms. For Fel d 1, 99.1% (SE = 0.7) of homes with an indoor cat and 55.7% (SE = 1.9) of homes without an indoor cat were above the sensitization threshold. In addition, 95.3% (SE = 1.6) of homes with an indoor cat and 15.7% (SE = 1.4) of homes without an indoor cat were above the asthma symptom threshold. The final model for the Fel d 1 house index among homes without an indoor cat contained the same predictors as in the unstratified model: region ($P < .001$), household income ($P = .001$), race ($P < .001$), and Hispanic ethnicity ($P = .026$).

DISCUSSION

Allergic sensitization to dog or cat allergens is a risk factor for asthma and asthma symptoms.[1,4,5,8,10,18,19] Exposures to Can f 1 and Fel d 1 as low as 2 µg/g and 1 µg/g, respectively, have been associated with an increased risk of sensitization.[8,10,17] Although it is thought that higher levels of exposure (from 8 to 10 µg/g) are needed to cause asthma symptoms among allergic patients,[17] several studies have shown that low-level exposures, such as those found in schools and homes without pets, can induce asthma symptoms.[20,21] This nationally representative study estimates that essentially all homes in the United States contain Can f 1 and Fel d 1. The majority of US homes have levels that exceed the proposed thresholds for sensitization to these allergens and about one-third of US homes have levels that exceed the proposed thresholds for asthma symptoms in sensitized asthmatics.

The universality of these allergens is remarkable when one considers that most US households have neither an indoor dog nor an indoor cat. This raises the obvious question about why these allergens are found in homes without pets. One explanation is that pets lived in the homes in the past and the allergens have persisted over time. Dog and cat allergens easily adhere to surfaces in the environment such as rugs, walls, and clothing, making the total elimination of the allergen from any environment very difficult.[22,23] However, in homes in which the pet has never been present, the pet allergen had to have been passively transported into the homes. Numerous studies have indicated that dog and cat allergens are transported on clothing, making them detectable in locations that are free of dogs and cats.[21,24-28] In fact, pet allergens have been detected in a variety of public places such as schools, trains, buses, hospitals, shopping mall stores, cinemas, hotels, pubs, and even in offices of allergists.[17,21,25,27,29]

In this study, several demographic characteristics, such as white race and non-Hispanic ethnicity, were independent predictors of elevated levels of Can f 1 and Fel d 1 even among homes without the indoor pet. In addition, these same demographic characteristics were predictive of a dog or cat in the home. Presumably, households with these demographic characteristics were more likely to transport pet allergen or have pet allergen transported into their homes from their communities, communities in which pet ownership was more prevalent. This suggests that the community is an important source of dog and cat allergens and that characteristics of the community are predictive of allergen levels in homes. This conclusion about the role of the community is consistent with the European Community Respiratory Health Survey, which reported positive correlations between the community prevalence of cats and rates of sensitization to cat, respiratory symptoms, physician-diagnosed asthma, and current asthma medication use.[30]

Within the homes, each of the pet allergens was highly correlated by sample location. Can f 1 and Fel d 1 are often associated with small particles that easily become airborne and remain airborne for long periods,[31,32] which would allow the allergens to circulate and settle throughout a house. Even with this distribution throughout the homes, the highest concentrations of Can f 1 and Fel d 1 were typically found on the sofa. In homes with the pets, the higher levels on sofas could reflect where pets prefer to spend time, but in any home, it could reflect the site most likely to come into contact with clothing worn outside the home. It could also reflect the persistence of allergen on sofas, particularly upholstered sofas, which are more difficult to clean than floors or bedding. Although it could be argued that the bed is the most relevant site for exposure to indoor allergens as people spend a large percentage of their time in bed, the sofa could potentially be an important site within the home for exposure to dog and cat allergens.

The major limitation to the NSLAH is its cross-sectional design. Dust samples were collected at a single point in time. In this national survey, it was not feasible to make repeated visits to the home. However, given the stated objective, which was to estimate and characterize indoor allergens levels in US homes, the cross-sectional design was the most efficient. Another limitation is that although kitchen dust samples were collected, only a proportion of them were analyzed for Can f 1 and Fel d 1. There were 2 reasons for this. First, because most kitchen floors were hard surface, the amount of dust per sample was limited. Cockroach and rodent allergens were given a higher priority in the laboratory analyses, and many of the dust samples were consumed by those analyses. Second, budgetary constraints prevented us from analyzing some kitchen samples for pet allergens even when dust was available. Of the kitchen floor samples analyzed, geometric mean concentrations (μg/g) of Can f 1 and Fel d 1 were 1.29 (SE = 0.28, N = 304) and 0.63 (SE = 0.10, N = 328), respectively. The major strength of the NSLAH is its national representativeness. The survey represented 96 million permanently occupied, noninstitutional housing units that permit resident children. The weighted characteristics of the surveyed homes compared favorably to those of other national housing surveys.[13]

In conclusion, Can f 1 and Fel d 1 are universally present in US homes. The implication of this for clinicians is that they can be assured that all of their allergy and asthma patients have some home exposure to dog and cat allergens. Even for patients without a dog or cat, if they live in communities with a high prevalence of pet ownership, their pet allergen exposures at home will likely be above allergic sensitization thresholds and may possibly be above levels that induce allergic symptoms. For pet-allergic patients in such communities, allergen avoidance may not be possible. For researchers, a major challenge is to develop environmental interventions that take into account the community as a potential reservoir for these allergens.

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