

Sensitization and Exposure to Pets: The Effect on Asthma Morbidity in the US Population



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What is already known about this topic? Both dog and cat ownership and sensitization are common in the United States. It is known that exposure to pets can increase asthma symptoms for those who are sensitized to the particular pet allergen.

What does this article add to our knowledge? Exposure to elevated levels of dog or cat allergen in the bedrooms of sensitized patients with asthma increases the number of asthma attacks dramatically. Using data from a study based on the US population, this study quantifies that increase on a national level.

How does this study impact current management guidelines? This study highlights the importance of implementing environmental allergen control in homes of patients with asthma who are sensitized to and have pets at home.

BACKGROUND: Although pets are found in more than 50% of US homes, the effect of pet allergen exposure on asthma morbidity in the US population is not well documented.

OBJECTIVE: To determine the effect of dog and cat allergen exposures on asthma morbidity in the US population.

METHODS: The National Health and Nutrition Examination Survey is a representative sample of civilian US population. Data

on asthma, dog and cat allergen levels in bedroom dust, as well as specific IgE to dog and cat were analyzed for all participants 6 years or older.

RESULTS: Pets are common in the United States, with more than 50% of households having a dog or a cat or both. The prevalence of allergic sensitization in the National Health and Nutrition Examination Survey population was similar for dog and cat, with both being approximately 12%. Among those who were sensitized, exposure to elevated levels of pet allergens was associated with an increased prevalence of asthma and asthma attacks. Indeed, 44.2% of the asthma attacks were attributable to exposure to high levels of dog allergen in the bedroom among patients with asthma sensitive to dog and 30.3% were attributable to cat allergen exposure among the comparable cat-sensitive and exposed group. Projecting these results to the US population indicates more than 1 million increased asthma attacks each year for the dog-sensitive and exposed group and more than 500,000 increased asthma attacks for the cat-sensitive and exposed population of patients with asthma.

CONCLUSIONS: Exposure to elevated levels of dog and cat allergens among those sensitized individuals with asthma is associated with excess asthma attacks. Reducing pet allergen exposures has the potential for a significant decrease in asthma morbidity. Published by Elsevier Inc. on behalf of the American Academy of Allergy, Asthma & Immunology (*J Allergy Clin Immunol Pract* 2018;6:101-7)

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The influence of pets in the development of asthma, allergy, and exacerbation of existing asthma is complicated. Sensitization to dog and/or cat allergen in early life is a strong predictor of the development of childhood asthma.¹ The National Health and Nutrition Examination Survey (NHANES) III found that more

Abbreviations used

NCHS- National Center for Health Statistics

NHANES- National Health and Nutrition Examination Survey

UAS- universal allergen standard

cases of asthma could be attributed to sensitization to cat allergen than any other sensitization.² On the contrary, other investigations have demonstrated a protective effect of pets in early life on developing sensitization^{3,4} and asthma.¹

However, it is known that when sensitized individuals with asthma are exposed to allergens to which they are sensitized, their asthma can become more severe and/or difficult to manage.⁵ To date, the impact of dog and cat allergen exposures on asthma morbidity among sensitized individuals has not been investigated at the national level, although sensitization to dog (11.8%) and cat (12.1%) is common in the US population,⁶ and pet ownership is even more common—a 2012 American Veterinary Medical Association survey reported 36.5% of US households having a dog and 30.4% having a cat.⁷ The NHANES 2005-2006 is the first study of a nationally representative sample to collect dust from US homes, analyze the dust for dog and cat allergens, draw blood to assess dog and cat sensitization, and evaluate asthma morbidity. The home dust allergen assay data did not become available until 2014 because of delays in the laboratory analysis phase of this component.⁸ These data offer a unique opportunity to determine the importance of dog and cat exposure on asthma morbidity in the US population.

METHODS

The NHANES 2005-2006 was a population-based survey conducted by the National Center for Health Statistics (NCHS) to determine the health and nutritional status of the civilian, noninstitutionalized US population. Its protocol was approved by the NCHS Institutional Review Board.⁹ Signed consent was obtained from all participants 18 years and older. For minors, a parent/guardian provided permission to participate and written assent was provided by children aged 7 to 17 years.

Trained technicians collected a single, combined sample of dust from the participant's bedroom bed and floor using a standardized protocol.⁸ A detailed description of dust collection, storage, and processing is provided in this article's Online Repository at www.jaci-inpractice.org. Dust samples were assayed for allergen concentrations using the universal allergen standard (UAS) and the MARIA assay (Indoor Biotechnologies, Charlottesville, Va). UAS values can be easily converted to earlier ELISA measures to compare with previously published values (see Table E1 in this article's Online Repository at www.jaci-inpractice.org).¹⁰ Endotoxin levels were assessed with *Limulus* amoebocyte lysate assay.¹¹

Participants 6 years and older were tested for allergen-specific IgE antibodies to dog and cat dander with the ImmunoCAP 1000 System (Pharmacia Diagnostics, Kalamazoo, Mich), now known as Thermo Scientific ImmunoCAP specific IgE. The upper and lower limits of detection (LLOD) were 1000 kU/L and 0.35 kU/L, respectively. For samples less than the LLOD, the NHANES provided a value equal to the LLOD divided by the square root of 2; for those more than the upper limit, the NHANES provided a value of 1000 kU/L.

Outcome definitions

A participant was considered to have physician-diagnosed current asthma when the participant responded in the affirmative to the following questions: "Has a doctor or other health professional ever told you that you have asthma?" and "Do you still have asthma?"

Only participants with physician-diagnosed current asthma were questioned about asthma attacks ("During the past 12 months, have you had an episode of asthma or an asthma attack?") and about emergency care visits ("During the past 12 months have you had to visit an emergency room or urgent care center because of asthma?").

Sensitization to each allergen was defined as a specific IgE concentration of 0.35 kU/L or more. Elevated pet allergen levels were defined by literature-based morbidity thresholds for cat and dog (8 µg/g and 10 µg/g, respectively) on the basis of previous ELISA standards, which were converted to compare directly with the data generated by the use of the UAS in the MARIA assay (3.19 µg/g and 2.11 µg/g, respectively).¹⁰

Statistical analyses

Specific IgE and cat and dog allergen concentrations were log-transformed to establish normality. Differences in prevalence of sensitivity, exposure, and pet ownership across population characteristics were tested with the chi-square statistic.

The primary association of interest was between sensitivity and exposure (dichotomized at the morbidity threshold for each allergen) and asthma. Unadjusted and adjusted log odds were estimated with logistic regression and then converted to differences in probabilities by using the inverse-logit function $p = \exp[\alpha]/(1 + \exp[\alpha])$.¹² Differences were adjusted for age, sex, race/ethnicity, poverty index ratio, serum cotinine levels, and endotoxin. Interaction effects were assessed using a 2-way interaction between sensitivity and exposure.

Statistical significance was established a priori at .05 for main effects and .10 for interactions. The sample weight variable (WTAL2YR) was created by NCHS and used in all analyses to account for the analytic subsample to obtain unbiased national estimates. The survey design variables representing the sampling strata (SDMVSTRA) and PSU (SDMVPSU) were used to calculate the SEs for the complex survey design. Analyses were performed with R version 3.2 and survey package version 3.30¹² (R Foundation for Statistical Computing, Vienna, Austria) to adjust for the complex sampling design and confirmed with SAS version 9.1.3 (SAS Institute, Inc, Cary, NC) survey sampling procedures.

RESULTS

Of the 5845 participants in the home allergen sample aged 6 years or older, 5238 (89.6%) had blood drawn to assess allergen-specific IgE levels and home dust samples collected to measure allergen levels. No significant differences were noted between the full sample and this analytic subsample.

Pet ownership and pet allergen exposures

Current pet ownership was common, with 51.2% of the participants reporting either a dog (37.9%; SE = 1.99) or a cat (27.5%; SE = 1.81) present in their home and 14.3% reporting both (Table I and Figure 1, A). Among those with asthma, pet ownership was slightly higher, with 42.2% of the households having a dog and 31.2% owning a cat. Pet ownership varied across sociodemographic groups, with both dog and cat ownership being significantly more common among those who were

TABLE I. Demographic characteristics of pet ownership, pet sensitization, and pet allergen exposure

Variable	Level	n*	Dog						Cat					
			Ownership		Exposure		Sensitivity		Ownership		Exposure		Sensitivity	
			% (SE)	P value	% (SE)	P value	% (SE)	P value	% (SE)	P value	% (SE)	P value	% (SE)	P value
Overall		5238	37.9 (1.99)		36.0 (2.21)		12.1 (0.64)		27.5 (1.81)		29.8 (1.76)		12.4 (0.67)	
Sex	Male	2586	38.1 (2.20)	.81	35.7 (2.47)	.74	13.5 (0.81)	.005	26.5 (1.76)	.20	27.3 (1.65)	<.001	13.4 (0.86)	.008
	Female	2652	37.7 (2.06)		36.2 (2.22)		10.7 (0.81)		28.5 (2.17)		32.2 (2.14)		11.4 (0.68)	
Age (y)	6-18	2008	46.2 (3.66)	<.001	44.9 (3.48)	<.001	14.9 (1.02)	<.001	30.0 (2.46)	<.001	32.2 (2.38)	<.001	13.2 (1.39)	.05
	19-59	2288	38.6 (2.22)		36.3 (2.38)		12.7 (0.80)		29.9 (2.14)		31.4 (2.09)		12.9 (0.71)	
	60-85+	942	27.1 (1.73)		25.8 (2.03)		7.2 (0.96)		16.9 (1.73)		21.9 (1.82)		9.8 (1.44)	
Race/ethnicity	Non-Hispanic white	2018	43.6 (2.27)	<.001	42.3 (2.60)	<.001	11.2 (0.81)	<.001	33.5 (2.04)	<.001	36.4 (1.61)	<.001	12.7 (0.87)	.01
	Non-Hispanic black	1442	13.6 (1.73)		10.1 (1.25)		17.4 (1.24)		6.9 (0.78)		7.4 (0.98)		13.1 (1.62)	
	Mexican American	1377	25.4 (2.13)		22.2 (1.79)		10.1 (1.14)		7.8 (1.03)		10.7 (1.20)		9.2 (0.98)	
	Other	401	37.0 (3.92)		33.2 (4.27)		13.9 (1.42)		27.0 (3.94)		26.4 (4.94)		11.8 (1.54)	
Education	<12th grade	1528	28.8 (3.79)	<.001	23.6 (3.29)	<.001	8.6 (0.87)	.007	18.8 (2.78)	.01	19.4 (3.38)	.004	8.9 (1.12)	.04
	12th grade	1279	43.6 (3.60)		39.2 (3.25)		12.6 (1.04)		26.7 (3.12)		29.5 (2.19)		13.1 (1.68)	
	>12th grade	2248	38.4 (2.41)		38.6 (2.55)		13.0 (1.03)		31.4 (2.63)		34.0 (2.05)		13.3 (0.98)	
Poverty index ratio	First (0-1.52)	1999	27.7 (2.88)	<.001	24.7 (2.90)	<.001	11.5 (1.18)	.87	18.2 (2.52)	<.001	21.1 (2.56)	<.001	10.8 (1.03)	.20
	Second (1.53-4.52)	2238	42.1 (2.64)		39.8 (2.63)		12.4 (1.03)		28.0 (2.55)		29.2 (1.89)		12.6 (0.90)	
	Third (4.53-5.0)	787	40.7 (3.39)		41.2 (3.64)		12.2 (1.57)		36.4 (3.76)		41.2 (3.06)		13.5 (1.43)	
Cotinine	First (0.01-0.02)	1304	36.9 (2.93)	.26	36.6 (3.36)	.19	10.9 (1.34)	.46	25.4 (3.55)	.38	27.4 (2.80)	.24	11.5 (1.23)	.48
	Second (0.03-22.30)	2915	36.6 (2.60)		34.2 (2.66)		12.6 (0.88)		27.2 (2.40)		29.7 (2.55)		12.8 (0.96)	
	Third (22.31-1156)	988	41.6 (2.56)		38.9 (2.28)		12.2 (0.95)		30.5 (1.89)		32.6 (1.99)		12.1 (0.75)	
Endotoxin	First (0.017-7.97)	1143	25.3 (2.61)	<.001	19.4 (2.44)	<.001	11.4 (1.50)	.52	23.9 (2.62)	.03	23.0 (1.86)	<.001	12.3 (1.09)	.80
	Second (7.98-33.40)	2550	39.3 (2.27)		39.0 (2.46)		11.8 (0.82)		27.7 (2.40)		30.9 (2.38)		12.1 (0.97)	
	Third (33.41-4723)	1545	47.6 (2.87)		46.5 (3.43)		13.3 (1.10)		30.8 (2.67)		34.4 (2.87)		13.0 (1.08)	

*Unweighted sample sizes calculated from exposure/sensitivity.

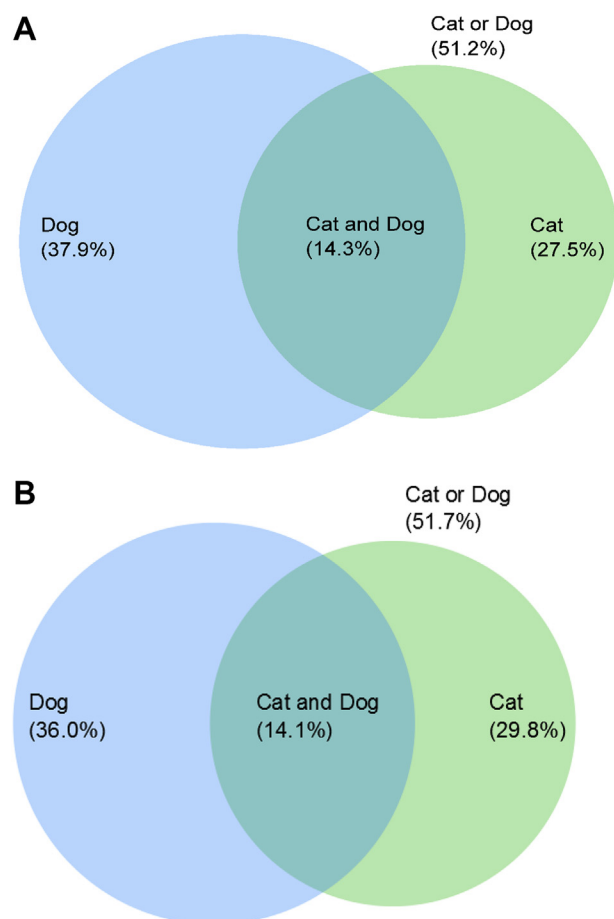


FIGURE 1. A, Ownership of cat and dog in the US population. B, Exposure to cat and dog allergen in the US population.

younger, non-Hispanic white, and with higher education and income (Table I).

In US homes, levels of dog allergen exposure exceeding the clinical threshold associated with asthma morbidity were present in 36.0% (SE = 2.21) of bedrooms (median, 0.451 µg/g), whereas the clinically relevant morbidity threshold for cat allergen was exceeded in 29.8% (SE = 1.76) of bedrooms (median, 0.260 µg/g) (Table I and Figure 1, B; see also Table E2 in this article's Online Repository at www.jaci-inpractice.org). Allergen levels exceeding the clinically relevant thresholds were more common for those who owned pets than for those who did not own pets (dog: 84.4% vs 6.7%; $P < .001$; cat: 90.2% vs 7.1%; $P < .001$). Allergen exposure varied across sociodemographic groups similar to pet ownership except that exposure to elevated levels of cat allergen was higher for females (32.2%) than for males (27.3%; $P < .001$) despite similar proportions of ownership (females 28.5% and males 26.5%; $P = .20$). Higher concentrations of dust endotoxin were significantly associated with both dog and cat ownership and exposure (Table I).

Allergen sensitivity and pet ownership

The rate of allergen sensitization was very similar for dog (12.1%; SE = 0.64) and cat (12.4%; SE = 0.67) (Table I). Pet allergen sensitization varied by sociodemographic factors, with lower rates of sensitization for dog and cat among females,

those aged 60 years or older, and lower levels of education. Mexican Americans and non-Hispanic whites had the lowest rates of sensitization to dog, whereas Mexican Americans had the lowest rates of sensitization to cat.

Sensitization was slightly higher for participants reporting ownership of that particular pet, but this difference was not significant. For dog owners, 12.2% were sensitized to dog allergen versus 12.1% ($P = .90$) of those not owning a dog. For cat owners, 13.9% were sensitized to cat allergen versus 11.9% ($P = .23$) of individuals not owning a cat. A family history of asthma was not related to pet ownership (dog: yes = 36.8% vs no = 36.2%; $P = .83$; cat: yes = 25.8% vs no = 26.9%; $P = .62$). Among individuals with a pet sensitivity, pet ownership of the pet to which the individual was sensitized was higher among patients with asthma than among those without (dog: 47% vs 35.3%; $P < .05$; cat: 39.7% vs 28.3%; $P = .09$). For cat, the levels of specific IgE increased with increasing levels of exposure ($P = .05$), whereas a small but statistically insignificant increase was seen for dog ($P = .21$) (see Figure E1 in this article's Online Repository at www.jaci-inpractice.org).

Impact of allergen sensitivity and exposure to pets on asthma morbidity

Current asthma and asthma attacks in the previous 12 months were examined to assess the impact of sensitization, exposure, and exposure conditional on sensitization using both adjusted and unadjusted models with similar results for both. Sensitization to either dog or cat increased both current asthma and asthma attacks in the past 12 months, whereas exposure to elevated allergen levels had little impact on either outcome (Table II). However, when pet allergen exposure was evaluated conditional on sensitization, among those not sensitized exposure had little to no impact on asthma outcomes, but among the sensitized there were increases for the outcomes for cat and dog (Figure 2; see also Table E3 in this article's Online Repository at www.jaci-inpractice.org). However, the combined effects of sensitivity and exposure were statistically significant only in each model for dog.

The impact of pet allergen exposures on the US population with asthma and sensitivity to pets

One of the strengths of a carefully stratified, population-based study with precise sampling procedures such as the NHANES is that inferences can be made to the general population with respect to the effect on disease morbidity (Table III). Applying the observed rates to the US population, we estimate that approximately 33.1% of those older than 6 years with asthma are also sensitive to dog allergen. The rate of attacks in this group was 23.3%. In contrast, the attack rate among those with asthma and sensitive to dog allergen but not exposed was 13.0%. This difference in attack rates allows us to estimate that 1,161,000 excess asthma attacks (44.2% of the total) occur each year as compared with a similar group not exposed to elevated levels of dog allergen in the bedroom.

Looking at cat we estimate that approximately 30% of those older than 6 years with asthma are also sensitive to cat allergen. The rate of attacks in patients with asthma sensitized to cat and exposed to elevated levels of cat allergen in the bedroom was 17.5%. In contrast, the attack rate among those with asthma and sensitive to cat allergen but not exposed was just 12.2%. Thus, there were 549,000 excess attacks (30.3% of the total) as

TABLE II. Exposure or sensitivity associations with asthma and asthma attacks (n = 5238)

Exposure	Outcome*	Model	Sensitivity				Exposure			
			Not sensitive, % (SE)	Sensitive, % (SE)	Sensitivity effect, % (95% CI)	P value	Not exposed, % (SE)	Exposed, % (SE)	Exposure effect, % (95% CI)	P value
Dog	Current asthma	Unadjusted	6.9 (0.59)	24.8 (3.92)	18.0 (9.7 to 26.2)	<.001	8.2 (0.79)	10.6 (1.10)	2.4 (−0.5 to 5.3)	.10
		Adjusted†	6.2 (0.67)	23.6 (3.89)	17.3 (9.3 to 25.4)	<.001	7.9 (0.91)	10.2 (1.46)	2.4 (−1.2 to 5.9)	.19
	Asthma attack in past 12 mo	Unadjusted	3.8 (0.30)	16.7 (2.75)	12.9 (7.5 to 18.3)	<.001	4.6 (0.65)	6.8 (0.78)	2.3 (0.1 to 4.5)	.04
		Adjusted	3.0 (0.41)	14.0 (2.30)	11.0 (6.6 to 15.4)	<.001	4.0 (0.58)	5.6 (1.17)	1.6 (−1.0 to 4.2)	.22
Cat	Current asthma	Unadjusted	7.2 (0.61)	21.9 (2.60)	14.6 (9.0 to 20.2)	<.001	9.0 (0.69)	9.2 (1.03)	0.2 (−2.2 to 2.6)	.88
		Adjusted	6.8 (0.72)	21.3 (2.71)	14.5 (8.8 to 20.1)	<.001	8.5 (0.81)	8.4 (1.24)	−0.2 (−2.8 to 2.5)	.90
	Asthma attack in past 12 mo	Unadjusted	4.2 (0.37)	13.9 (1.79)	9.7 (6.4 to 13.0)	<.001	5.3 (0.52)	5.5 (0.76)	0.2 (−1.5 to 1.9)	.80
		Adjusted	3.5 (0.48)	11.8 (1.45)	8.3 (5.7 to 11.0)	<.001	4.5 (0.53)	4.2 (0.89)	−0.4 (−1.9 to 1.2)	.64

*Outcomes for those with physician-diagnosed asthma and who still have asthma.

†Adjusted for age, sex, race/ethnicity, poverty index ratio, cotinine, and endotoxin.

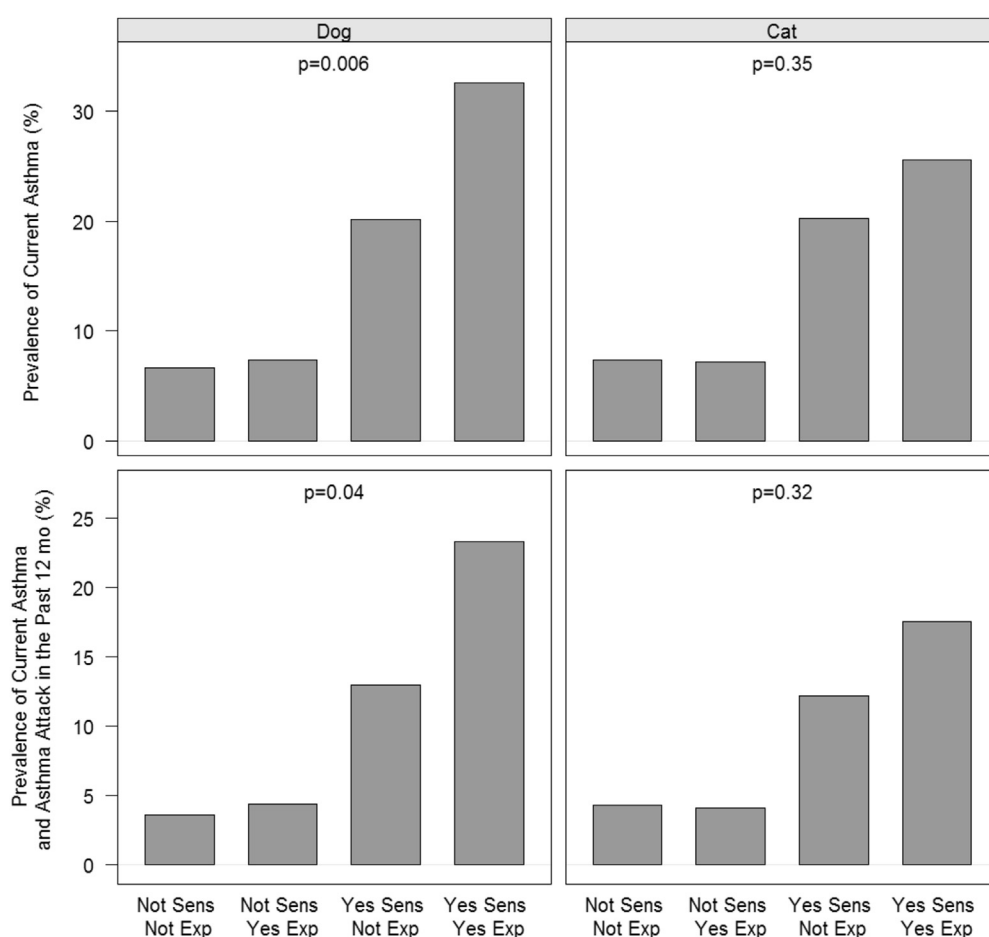


FIGURE 2. Unadjusted exposure and sensitivity associations with asthma.

compared with a similar group not exposed to elevated levels of cat allergen in the bedroom.

Asthma exacerbations leading to an emergency care visit have a considerably greater economic impact and here we find a similar pattern. The rate of these visits within a 12-month period for those with asthma who are both sensitive and exposed to elevated levels of dog allergen is 7.0%, compared with a rate of 3.9% for those

with asthma who are sensitive to dog allergen but not exposed. Among the dog-sensitized and exposed group, 349,000 (44.2%) of the total 789,000 emergency care visits were associated with exposure to elevated levels of dog allergen in the bedroom. Among the cat-sensitized and exposed group, 352,000 (47.2%) of the total 746,000 emergency care visits were associated with exposure to elevated levels of cat allergen in the bedroom.

TABLE III. Population projections for asthma attacks and emergency care visits for those with asthma and pet sensitivity

Asthma outcomes	Dog-sensitive (n = 28,833,000)		Cat-sensitive (n = 29,527,000)	
	Not exposed (n = 17,563,000)	Exposed (n = 11,270,000)	Not exposed (n = 19,159,000)	Exposed (n = 10,368,000)
Asthma attack in past 12 mo				
Asthma attacks	2,283,000 (13.0%)	2,626,000 (23.3%)	2,337,000 (12.2%)	1,814,000 (17.5%)
Expected asthma attacks*		1,465,000		1,265,000
Excess asthma attacks with exposure		1,161,000		549,000
% Attributed to exposure		44.2		30.3
Asthma emergency care visits in past 12 mo				
Asthma emergency care visits	685,000 (3.9%)	789,000 (7.0%)	728,000 (3.8%)	746,000 (7.2%)
Expected asthma emergency care visits*		440,000		394,000
Excess asthma emergency care visits		349,000		352,000
% Attributed to exposure		44.2		47.2

*Calculated on the basis of attack rate of unexposed.

DISCUSSION

Pet ownership, pet allergen exposure, and sensitization to pets are common in the US population and most common among population subgroups that typically are less likely to be at risk for adverse environmental exposures. Individuals with asthma who are sensitized and exposed to pet allergens have more asthma attacks and emergency care visits for asthma. We estimate that more than 1,700,000 excess asthma attacks and nearly 700,000 excess emergency care visits for asthma each year are associated with exposure to elevated levels of pet allergen in the bedroom among patients with asthma sensitive to pets. Medication use was not included in these analyses because the objective is to show the population impact of exposure and sensitization as it exists in the US population. Because the use of appropriate medication would be expected to reduce the impact of exposure, limiting our analyses to just untreated patients with asthma would overestimate the impact. It should be noted that pet allergen exposure in the absence of sensitization did not increase asthma attacks or unscheduled visits.

Home exposure to pet allergens may not reflect the total exposure burden, which could contribute to the inconsistent results with regard to cat. Several investigations have demonstrated that exposure to pet allergens, especially for cat, in schools and day care centers is prevalent and elevated exposure levels can be more common than those found in homes.¹³⁻¹⁵ The lower effect seen with cat allergen exposure in the bedroom most likely reflects the more frequent exposure to clinically relevant levels of cat allergen outside the bedroom. This other exposure could easily moderate the importance of the bedroom exposure.

When examining the relationship between pets and health outcomes, there is always a concern about individuals with a disease altering their pet-keeping habits as a result of their disease, thus leading to a reverse causality. Namely, those with the greatest sensitivity to cat or dog are the least likely to own pets, making it appear that the lowest levels of exposure (as found in the homes of non-pet owners) lead to higher sensitivity. Surprisingly, pet ownership was more common for both cats and dogs among those with asthma than those without asthma. Moreover, among sensitized patients with asthma, pet ownership of the pet to which they were sensitized was higher than among nonsensitized patients with asthma. The relationship of pet ownership among those with sensitization and asthma appears to

be complex. For example, the European Community Respiratory Health Survey found avoidance of cat ownership after the development of asthma or allergy but not so for dogs.¹⁶ In contrast, the NHANES 2005-2006 found no relationship between personal sensitization or family history of asthma and pet ownership.

These results provide some clarity to the somewhat inconsistent data of earlier studies of pet allergen sensitivity and asthma morbidity. In previous studies, dog allergen exposure was found to have a more consistent effect on asthma morbidity than cat allergen exposure. In a study of children with asthma, elevated levels of dog allergen among sensitized individuals as compared with nonsensitized individuals were associated with the Global Initiative for Asthma—determined asthma severity, wheezing, and controller medication use in the previous 12 months, whereas among those sensitized to cat allergen, exposure was associated only with asthma severity, as compared with those nonsensitized.¹⁷ The combination of sensitization and exposure to the sensitizing pet allergen has been associated with decreased lung function in early life in a European birth cohort study.¹⁸ Another study in Northern Sweden reported that the increasing level of IgE to cat or dog was associated with increased asthma severity and persistence.¹⁹ However, not all studies have found an effect of exposure to cat. The European Respiratory Health Survey observed no association for cat allergen measured in mattresses and asthma symptoms in the total or sensitized population.^{13-15,19,20}

The relationship between exposure to allergen levels and current sensitization is less clear. High levels of cat allergen during infancy have been shown to be positively correlated with sensitization at 2 years but not 6 years, whereas cat ownership during the first 6 years of life was associated with sensitization at age 6 years in a German birth cohort.²¹ In the United States, the Childhood Asthma Management Program observed that levels of dog and cat allergen in household dust were not related to sensitization rates.²² A study in Detroit of 9- to 12-year-old children revealed a linear increase in dog allergen-specific IgE associated with home allergen levels, but not for cat.²³ Other investigations have reported that high levels of allergen exposure may even induce a tolerance-like state.⁴

The national scope of the NHANES sample and the standardized method of data collection are among the greatest

strengths of this study. The systematic, complex sampling design of the NHANES enables researchers to make projections to the entire US population. This precision allows us to identify population-based relationships that may have important public health implications even in the absence of traditional statistical significance thresholds being met. For example, although the effects for cat sensitivity and exposure among patients with asthma are weaker than those observed for dog, the projected increase of more than half a million excess asthma attacks has important public health implications with regard to excess asthma morbidity and health care utilization. Although the data collection of the NHANES is quite extensive, it is only a single point in time reflecting current pet ownership and allergen exposure in just one room. Nonetheless, the relationship between pet allergen exposure and pet sensitivity among those with asthma appears to be quite clear and points to rather dramatic excess asthma morbidity and health care utilization in the US population.

A recent practice parameter advises sensitized individuals to not get a pet or remove pets from the environment or take measures to reduce exposure to the allergen.²⁴ These findings provide compelling evidence for that recommendation. The results from this NHANES investigation make clear that the combination of asthma, pet exposure, and pet sensitivity results in considerable excess asthma morbidity. With more than half of the US population owning pets and 1 out of 10 children having asthma, efforts to reduce allergen exposure could have a major impact on asthma morbidity and health care utilization.

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ONLINE REPOSITORY

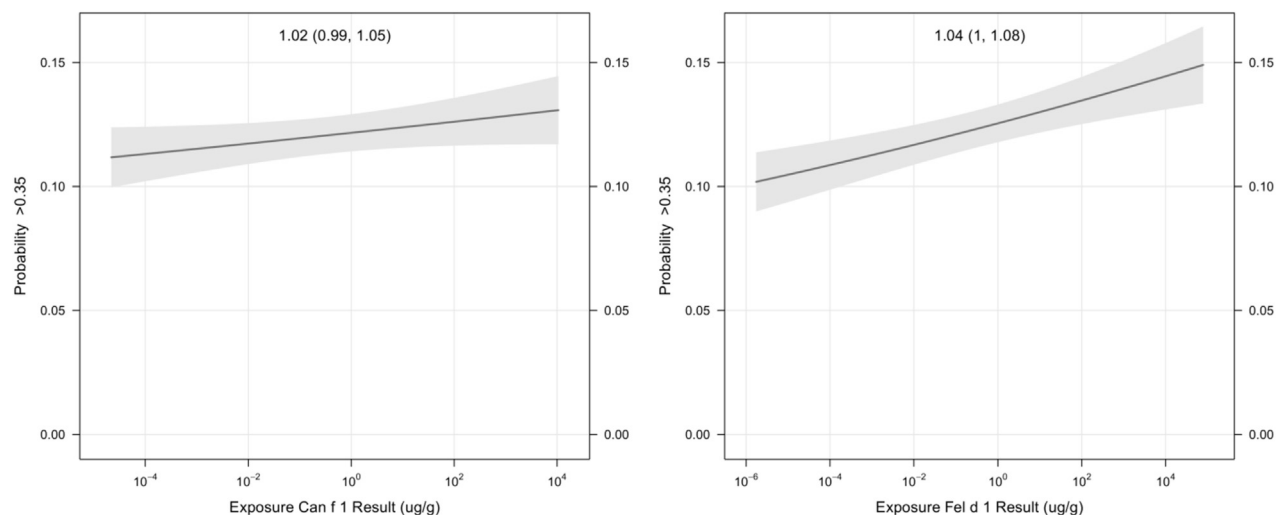


FIGURE E1. Association between exposure and sensitivity. Numbers are odds ratios and 95% CIs.

TABLE E1. Conversion between ELISA and UAS

Allergen	ELISA morbidity cutoff points (μg/g)	ELISA (μg/g) to (ng/mL) × (1000/20)	Regression converts ELISA to UAS ^{E1} (ng/mL)	Regression converts ELISA to UAS ^{E1} (ng/mL)	UAS conversion from (ng/mL) to (μg/g) × (20/1000)
A. Conversion from ELISA to UAS					
Canf1	10.0	500	$y = 0.22x - 4.56$	105	2.1088
Feld1	8.0	400	$y = 0.38x + 7.56$	159.6	3.1912
Allergen	UAS/MARIA (μg/g)	UAS/MARIA (μg/g) to (ng/mL) × (1000/20)	Regression converts ELISA to UAS ^{E1} (ng/mL)	Regression converts ELISA to UAS ^{E1} (ng/mL)	ELISA conversion from (ng/mL) to (μg/g) × (20/1000)
B. Conversion from UAS to ELISA					
Canf1	2.11	105.5	$x = (y + 4.56)/0.22$	500	10.0
Feld1	3.19	159.5	$x = (y - 7.56)/0.38$	400	8.0

Note. y = UAS/MARIA and x = ELISA.

TABLE E2. Exposure distributions

Statistic	Dog (μg/g UAS)	Cat (μg/g UAS)
Minimum	0.009*	0.003*
1st percentile	0.009*	0.003*
5th percentile	0.009*	0.003*
10th percentile	0.009*	0.009
20th percentile	0.032	0.028
30th percentile	0.068	0.064
40th percentile	0.178	0.125
Median	0.451	0.260
60th percentile	1.211	0.646
70th percentile	4.74	3.16
80th percentile	16.3	22.4
90th percentile	48.0	110.1
95th percentile	96.5	234.9
99th percentile	268.1	751.1
Maximum	1216.4	2944.7

Note. Dog exposure >2.11 (μg/g UAS) = 36.0 percentile; cat exposure >3.19 (μg/g UAS) = 29.8 percentile.

*Less than lower limit of detection.

TABLE E3. Exposure and sensitivity associations with asthma and asthma attacks (n = 5238)

Exposure	Outcome*	Model	Not sensitive				Sensitive			
			Not exposed, % (SE)	Exposed, % (SE)	Exposure effect, % (95% CI)	P value	Not exposed, % (SE)	Exposed, % (SE)	Exposure effect, % (95% CI)	Interaction P
Dog	Current asthma	Unadjusted	6.7 (0.69)	7.4 (1.36)	0.7 (−2.5 to 3.9)	.67	20.1 (4.34)	32.6 (4.77)	12.5 (3.6 to 21.4)	.006
		Adjusted†	6.3 (0.78)	6.7 (1.46)	0.4 (−2.9 to 3.7)	.81	18.5 (4.06)	32.7 (4.73)	14.2 (4.2 to 24.2)	.005
Asthma attack in past 12 mo		Unadjusted	3.6 (0.42)	4.3 (0.88)	0.7 (−1.5 to 3.0)	.53	13.0 (3.46)	23.3 (4.14)	10.3 (0.6 to 20.1)	.04
		Adjusted	3.0 (0.50)	3.3 (0.92)	0.3 (−1.8 to 2.4)	.76	10.7 (2.54)	20.2 (4.58)	9.5 (−1.4 to 20.4)	.09
Cat	Current asthma	Unadjusted	7.3 (0.60)	7.2 (1.26)	−0.2 (−2.8 to 2.4)	.89	20.2 (3.42)	25.5 (4.81)	5.3 (−5.9 to 16.5)	.35
		Adjusted	7.1 (0.75)	6.0 (1.36)	−1.1 (−3.9 to 1.6)	.41	19.7 (3.22)	23.6 (4.47)	3.9 (−7.3 to 15.1)	.49
Asthma attack in past 12 mo		Unadjusted	4.3 (0.41)	4.1 (0.61)	−0.2 (−1.6 to 1.1)	.77	12.2 (2.43)	17.5 (4.35)	5.3 (−5.2 to 15.9)	.32
		Adjusted	3.8 (0.49)	2.7 (0.66)	−1.1 (−2.2 to 0.0)	.04	10.3 (1.88)	13.9 (3.57)	3.6 (−5.4 to 12.6)	.44

*Outcomes for those with physician-diagnosed asthma and who still have asthma.

†Adjusted for age, sex, race/ethnicity, poverty index ratio, cotinine, and endotoxin.

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