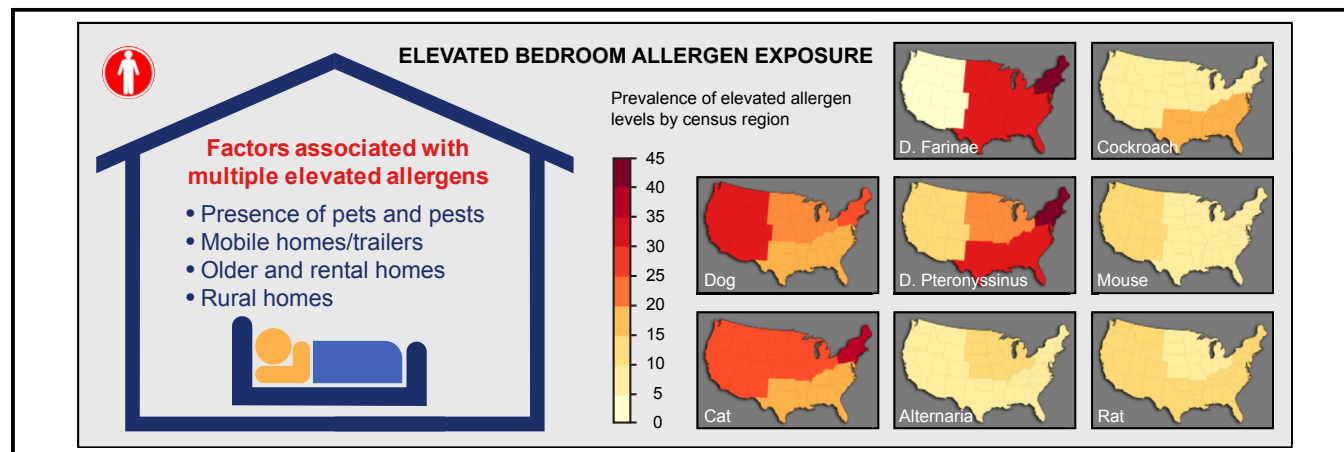


Bedroom allergen exposures in US households

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GRAPHICAL ABSTRACT



Background: Bedroom allergen exposures contribute to allergic disease morbidity because people spend considerable time in bedrooms, where they come into close contact with allergen reservoirs.

Objective: We investigated participant and housing characteristics, including sociodemographic, regional, and climatic factors, associated with bedroom allergen exposures in a nationally representative sample of the US population.

Methods: Data were obtained from National Health and Nutrition Examination Survey 2005-2006. Information on participant and housing characteristics was collected by using questionnaires and environmental assessments. Concentrations of 8 indoor allergens (Alt a 1, Bla g 1, Can f 1, Fel d 1, Der f 1, Der p 1, Mus m 1, and Rat n 1) in dust vacuumed from nearly 7000 bedrooms were measured by using immunoassays.

Exposure levels were classified as increased based on percentile (75th/90th) cutoffs. We estimated the burden of exposure to

multiple allergens and used multivariable logistic regression to identify independent predictors for each allergen and household allergen burden.

Results: Almost all participants (>99%) had at least 1 and 74.2% had 3 to 6 allergens detected. More than two thirds of participants (72.9%) had at least 1 allergen and 18.2% had 3 or more allergens exceeding increased levels. Although exposure variability showed significant racial/ethnic and regional differences, high exposure burden to multiple allergens was most consistently associated with the presence of pets and pests, living in mobile homes/trailers and older and rental homes, and living in nonmetropolitan areas.

Conclusions: Exposure to multiple allergens is common. Despite highly variable exposures, bedroom allergen burden is strongly associated with the presence of pets and pests. (J Allergy Clin Immunol 2017;■■■:■■■-■■■.)

Key words: Allergen, indoor, exposure, home, allergy

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The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the RDC, the NCHS, or the US Centers for Disease Control and Prevention.

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Abbreviations used

LLOD:	Lower limit of detection
MARIA:	Multiplex Array for Indoor Allergens
NCHS:	National Center for Health Statistics
NHANES:	National Health and Nutrition Examination Survey
NSLAH:	National Survey of Lead and Allergens in Housing
PIR:	Poverty index ratio
SES:	Socioeconomic status
sIgE:	Specific IgE

Indoor allergen exposures are important risk factors of allergic respiratory disease because people spend a large portion of their time indoors, especially at home.¹⁻³ Although the relationship between allergen exposures and development of allergic sensitization and disease is complex and not fully understood,¹ indoor allergens can trigger and exacerbate asthma and allergy symptoms in sensitized subjects.^{1,2,4-8} Despite extensive research, most indoor allergen studies have focused on selected high-risk populations (eg, asthmatic subjects, children, and inner-city populations), single allergens, or both.^{2,9-11} Recently released data from the National Health and Nutrition Examination Survey (NHANES) provide the largest resource to date for assessment of indoor allergen exposures in a nationally representative sample of the US population,¹² following the National Survey of Lead and Allergens in Housing (NSLAH), which was conducted on a much smaller scale in 1998-1999.¹³ NHANES 2005-2006 assessed residential indoor allergen levels in bedroom dust collected from nearly 7000 US households.

Bedrooms are often considered an important site for allergen exposure not only because of the time spent in bed but also because of the close proximity of allergen reservoirs (eg, bedding) to a person's breathing zone and associated reservoir disturbances.¹⁴ Recent studies demonstrate that a significant fraction of airborne particles, which are resuspended by human movements in bed, can be inhaled during sleep.^{15,16} Although residential exposures can vary spatially and temporally, several studies link bedroom allergen exposures to allergic sensitization and disease morbidity,¹⁷ especially among those who are exposed to increased levels of the allergen or allergens to which they are sensitized.⁴⁻⁷

To advance our knowledge of the prevalence and determinants of indoor allergen exposures, we investigated the importance of different sociodemographic and housing factors in residential allergen exposures. This article provides the most comprehensive report on bedroom allergen exposures in US households, estimating the exposure burden to individual and multiple allergens and identifying independent predictors of these exposures. To date, no study has provided such detailed information on how allergen levels vary by regional and climatic factors, as well as by level of urbanization. Because NHANES 2005-2006 is the first large population-based study to enable comparisons between exposure and sensitization patterns in the general US population, we also discuss sociodemographic similarities and differences between allergen exposures and the previously reported sensitization patterns.¹⁸

METHODS**Study data and design**

Data were collected as part of NHANES 2005-2006, which used a complex multistage probability sampling design to select a sample of the civilian, noninstitutionalized US population. The survey oversampled adolescents (aged 12-19 years), elderly persons (aged ≥ 60 years), African Americans, Mexican Americans, and low-income persons to ensure adequate samples for subgroup analyses. Information on participant and housing characteristics was obtained by using questionnaires,¹⁹⁻²¹ as well as environmental assessments (eg, room temperature and relative humidity were assessed with a digital hygrothermometer).²²

NHANES 2005-2006 included a component that assessed indoor allergen levels in reservoir dust samples collected from participants' bedrooms. A detailed description of the study procedures is available in the NHANES Allergen Dust Collection Procedures Manual.²² Because of delays in the laboratory analysis phase of this component, dust data were not available until 2014. Our data analysis is limited to participants with dust data available ($n = 6963$).

Table E1 in this article's Online Repository at www.jacionline.org shows selected population characteristics of the NHANES 2005-2006 participants. To protect participant confidentiality, all data analysis using restricted and not publicly available variables (census region, level of urbanization, climate region, and presence of children in the household) was conducted at the National Center for Health Statistics (NCHS) Atlanta Research Data Center. All restricted variables were provided, created, or both by the NCHS. The climate regions were determined based on the guidelines of the US Department of Energy Building America Program, which use heating degree days, average temperatures, and precipitation to differentiate each region.²³ To avoid data suppression caused by small cell sizes, 8 US climate regions were aggregated into 4 categories: subarctic/very cold/cold; mixed-humid/marine; hot-humid; and mixed-dry/hot-dry.

The survey protocol was approved by the NCHS Ethics Review Board,²⁴ and written informed consent was obtained from all participants. Information on the NHANES survey design and implementation can be found at http://www.cdc.gov/nchs/nhanes/survey_methods.htm.²⁵

Exposure assessment

Participants aged 1 year and older were eligible for dust allergen testing. Dust samples were collected from each participant's bed and bedroom floor with a Sanitare Model 3683 Vacuum Cleaner and a Mitest Dust Collector (Indoor Biotechnologies, Charlottesville, Va). For a combined sample, each sampling location (1 square yard) was vacuumed for 2 minutes, and allergen levels were assessed with immunoassays. Concentrations of dog (Can f 1), dust mite (Der f 1 and Der p 1), cat (Fel d 1), *Alternaria alternata* (Alt a 1), mouse (Mus m 1), and rat (Rat n 1) allergens were assessed with the Multiplex Array for Indoor Allergens (MARIA; Indoor Biotechnologies), whereas concentrations of cockroach allergen (Bla g 1) were measured with an ELISA.¹² For allergens assessed with MARIA, the lower limit of detection (LLOD) varied from 0.002 to 0.013 $\mu\text{g/g}$. The lowest LLOD for Bla g 1 was 0.002 U/g. Fill values equal to the allergen-specific LLOD divided by the square root of 2 were used for samples less than the LLOD to maximize the number of samples in the analyses.¹² Details of the laboratory methods and quality control procedures are published elsewhere.^{26,27}

Statistical analysis

Allergen concentrations were dichotomized to high and low to medium levels to estimate exposure to increased allergen levels and the burden to multiple allergens. Because clinically relevant thresholds have not been established for all measured allergens, we used percentile cutoffs to ensure a consistent analytic approach across all allergens. For allergens that had relatively nonskewed distributions, allergen exposures were classified as increased if the allergen concentration exceeded the 75th percentile (Can f 1, 8.472 $\mu\text{g/g}$; Fel d 1, 6.369 $\mu\text{g/g}$; Der f 1, 0.338 $\mu\text{g/g}$; and Der p 1, 0.219 $\mu\text{g/g}$). For allergens with skewed distributions, a cutoff of the 90th percentile was

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