House dust mite allergen in US beds: Results from the first National Survey of Lead and Allergens in Housing

Samuel J. Arbes, Jr, PhD,[a] Richard D. Cohn, PhD,[b] Ming Yin, PhD,[b] Michael L. Muilenberg, MS,[c] Harriet A. Burge, PhD,[c] Warren Friedman, PhD,[d] and Darryl C. Zeldin, MD[a] *Research Triangle Park and Durham, NC, Boston, Mass, and Washington, DC*

Background: Although exposure to house dust mite allergen is a major risk factor for allergic sensitization and asthma, nationwide estimates of dust mite allergen levels in US homes have not been reported.

Objective: The purpose of this study was to estimate the prevalence of dust mite allergen in beds of US homes and to identify predictors of dust mite allergen concentration.

Methods: Data were obtained from the first National Survey of Lead and Allergens in Housing, a cross-sectional survey of 831 permanently occupied noninstitutional housing units that permitted resident children. Dust mite allergen concentration (Der f 1 plus Der p 1) was determined from a dust sample collected from a bed. The percentages of homes with concentrations at or greater than detection, 2.0 μg/g bed dust, and 10.0 μg/g bed dust were estimated. Independent predictors of allergen concentration were assessed with multivariable linear regression.

Results: The percentages of US homes with dust mite allergen concentrations at or greater than detection, 2.0 μg/g, and 10.0 μg/g were 84.2% (SE, 1.73), 46.2% (SE, 2.0), and 24.2% (SE, 2.1), respectively. Independent predictors of higher levels were older homes, non-West census regions, single-family homes, no resident children, lower household income, heating sources other than forced air, musty or mildew odor, and higher bedroom humidity.

Conclusion: Most US homes have detectable levels of dust mite allergen in a bed. Levels previously associated with allergic sensitization and asthma are common in US bedrooms. Predictors can be used to identify conditions under which homes are more likely to have increased dust mite allergen levels. (J Allergy Clin Immunol 2003;111:408-14.)

Key words: *House dust mite allergen, indoor allergens, surveys, epidemiology*

Environmental and occupational disorders

Abbreviations used

NIEHS: National Institute of Environmental Health Sciences

NSLAH I: First National Survey of Lead and Allergens in Housing

PSU: Primary sampling unit

The prevalence of asthma in the United States has increased steadily since 1980.[1] Because this increase in prevalence has coincided with an increase to approximately 90% in the percentage of time individuals spend indoors,[2] it has been suggested that the indoor environment might play a role in the cause of asthma. Of particular interest to researchers and clinicians is the relationship between indoor allergens, allergic sensitization, and asthma. The most thoroughly studied indoor allergens are the group 1 allergens Der f 1 and Der p 1 derived from the dust mite species *Dermatophagoides farinae* and *Dermatophagoides pteronyssinus*, respectively. Exposure to dust mite allergen, especially in atopic children, is associated with the development of sensitization to the allergen,[3-6] and sensitization to dust mite allergen is a major independent risk factor for asthma.[7-13] Dust mite allergen concentrations of 2 and 10 μg/g bed dust have been proposed as thresholds of exposure for the development of allergic sensitization and asthma, respectively.[3-6,14,15] However, there is evidence that sensitization occurs at much lower concentrations.[16]

Although the evidence for a causal relationship between indoor allergens and asthma is most complete for dust mite allergens,[11] estimates of exposure in a nationally representative sample of homes have not been reported. Previous studies have focused on specific geographic areas or were designed to examine the relationship between exposure and sensitization or disease, as opposed to providing population-based estimates of exposure. The objectives of this article were to (1) estimate the prevalence of dust mite allergen in beds of US homes, (2) compare dust mite allergen levels between various housing characteristics, and (3) identify independent predictors of dust mite allergen concentration. It is hoped that this article will document the magnitude of the problem of dust mite allergen exposure, provide a baseline for following trends in exposure over time, con-

From [a]the Division of Intramural Research, National Institute of Environmental Health Sciences, Research Triangle Park; [b]Analytical Sciences, Inc, Durham; [c]the Department of Environmental Health, Harvard School of Public Health, Boston; and [d]the US Department of Housing and Urban Development, Office of Healthy Homes and Lead Hazard Control, Washington.

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Reprint requests: Darryl C. Zeldin, MD, NIEHS/NIH, 111 Alexander Dr, Mail Drop D2-01, Research Triangle Park, NC 27709.

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TABLE I. Median and mean dust mite allergen concentrations (in micrograms per gram) distributed by general housing unit characteristics

Characteristic	n	Median	Geometric mean (SE)	*P* value
Total	736	1.53	1.40 (0.18)	—
Construction year				
1978-1998	202	0.53	0.65 (0.12)	
1960-1977	229	1.51	1.37 (0.40)	
1940-1959	168	3.80	2.55 (0.58)	
1939 or earlier	137	2.51	2.69 (0.68)	<.001
1990 census region				
West	177	0.15	0.31 (0.06)	
Midwest	174	1.16	1.50 (0.36)	
South	249	2.35	1.84 (0.43)	
Northeast	136	3.05	3.35 (1.08)	<.001
Metropolitan statistical area				
Yes	613	1.48	1.36 (0.17)	
No	123	1.95	1.52 (0.56)	.78
Housing unit type				
Multifamily	106	1.47	1.07 (0.29)	
Single family	630	1.51	1.46 (0.18)	.21
Tenure				
Owner occupied	482	1.48	1.42 (0.19)	
Renter occupied	251	1.80	1.37 (0.33)	.88
No. of persons in household				
4-9	257	1.61	1.33 (0.23)	
2-3	373	1.16	1.24 (0.19)	
1	106	2.83	2.21 (0.68)	.20
Child resident <18 y of age				
Yes	362	1.08	0.97 (0.16)	
No	371	2.17	1.80 (0.32)	.01
Household income				
≥$60,000	174	0.71	0.83 (0.21)	
$40,000-$59,999	133	1.00	1.13 (0.32)	
$20,000-$39,999	212	2.35	2.07 (0.49)	
<$20,000	159	2.84	2.42 (0.47)	.004
Race of youngest member				
Nonwhite	170	1.67	1.15 (0.23)	
White	551	1.59	1.51 (0.22)	.27
Ethnicity of youngest member				
Hispanic	77	1.49	1.32 (0.35)	
Non-Hispanic	652	1.59	1.43 (0.21)	.83
Education (highest attained by any member)				
Above high school	398	1.28	1.34 (0.28)	
High school diploma (GED) or less	170	3.14	2.57 (0.56)	.06

firm findings of smaller observation studies, provide information to clinicians about the likelihood of a patient's exposure, and generate hypotheses for future intervention trials.

METHODS

Study data and design

Data for this study were obtained 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. This cross-sectional survey used a complex, multistage design to sample the US population of permanently occupied noninstitutional housing units that permit resident children. A detailed description of the methodology is published elsewhere[17]; however, an overview of housing unit selection is presented here. First, 75 primary sampling units (PSUs) consisting of metropolitan statistical areas or counties were selected among the 1404 PSUs in the continental United States. A PSU's probability of selection was proportional to its 1990 census population. A map of the 75 PSUs can be found elsewhere.[17] Second, approximately 10 segments, each consisting of one or more contiguous blocks, were selected per PSU. A segment's probability of selection was proportional to its number of housing units. Third, 39,071 housing units were identified within the selected segments, 1984 were randomly selected for recruitment, and 831 were surveyed. A detailed discussion of nonresponse was published previously.[17] The surveyed housing units were weighted to represent their overall probability of selection and to correct for nonresponse.[17] The NSLAH I study population represents 96 million permanently occupied noninstitutional housing units that allow resident children. For each housing unit surveyed, a questionnaire was administered to a household member, vacuumed dust samples were collected from multiple sites, and observations were recorded. Although this article focuses

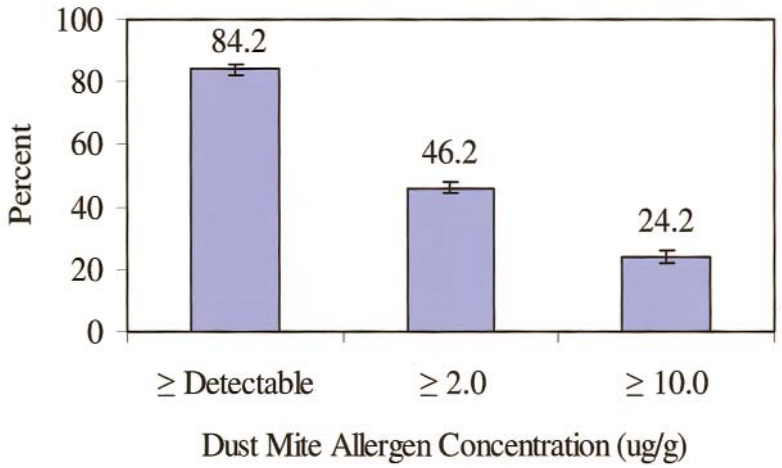

FIG 1. Percentage (SE) of US homes with dust mite allergen (Der f 1 plus Der p 1) at or greater than 3 concentration thresholds.

on dust mite allergen in the bed, future articles will examine other allergens and other sites within the home as NSLAH I data become available. The NSLAH I was approved by the NIEHS Institutional Review Board on June 16, 1998.

Measurement of dust mite allergen

One bedroom was randomly selected from among the bedrooms in which children slept. If no children resided in the home, then a bedroom was randomly selected from among regularly occupied bedrooms in the home. A dust sample was collected from a bed by using the Eureka Mighty-Mite 7.0-ampere vacuum cleaner (Eureka Co). A 19 mm × 90 mm cellulose extraction thimble (Whatman International, Ltd) was fitted into the distal end of the vacuum's extension tube, sealed with a rubber O ring, and covered with a clean crevice tool. Bedding was vacuumed for a total of 5 minutes: bedding layers for 2.5 minutes, the top surface of the mattress for 2.0 minutes, and a pillow for 0.5 minutes. Fully encasing impermeable mattress covers were not removed. Dust samples were stored in a freezer at –20°C until processed and analyzed.

At the laboratory, dust samples were sieved through a 425-μm pore grating 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. Concentrations of the allergens Der f 1 and Der p 1 were measured separately with mAb-based ELISAs[18] and reported in micrograms of allergen per gram of dust. The lower limit of detection for each allergen was 0.025 μg/g for most samples; however, because of limited amounts of dust in some samples, 18 Der f 1 and 36 Der p 1 assays had lower limits of detection from 0.05 to 0.425 μg/g.

Statistical analyses

For statistical analyses, concentrations of the allergens Der f 1 and Der p 1 were summed. Descriptive statistics for the overall distribution of dust mite allergen concentrations were generated. Median and mean (geometric) concentrations were estimated for categories of each housing characteristic. Comparisons of log-transformed means were assessed with ANOVA. Characteristics in Tables I and II with *P* values less than or equal to .25 were selected for multivariable linear regression. Before modeling, some multiple categories were combined. Education was not modeled because of a large number of missing observations, and the use of a dehumidifier was not modeled because of colinearity with frequent musty and mildew odor. Starting from a full main-effects model, variables with the highest Wald F *P* value were dropped until only variables with *P* values less than or equal to .10 remained. For the independent predictors identified in the final linear regression model, geometric mean concentrations adjusted for the other predictors in the model were computed.

Sample weights were applied to all estimates to account for housing unit selection probabilities, nonresponse, and poststratification. Taylor series linearization methods were used to obtain variance estimates adjusted for clustering associated with the multistage complex survey design. All statistical analyses were conducted with SUDAAN, Release 7.50 (Research Triangle Institute).

RESULTS

Prevalence of dust mite allergen

The continuous distribution of dust mite allergen concentrations for the beds was highly skewed. The minimum, median, and maximum concentrations were 0.01, 1.53, and 519 μg/g, respectively. The arithmetic and geometric means were 15.7 μg/g (SE, 2.25) and 1.40 μg/g (SE, 0.18), respectively. Because of the skewed distribution, concentration values were log transformed for all comparisons of means.

Fig 1 shows the percentage of US homes that had concentrations of dust mite allergen at or greater than detection, 2.0 μg/g, and 10.0 μg/g. Most homes (84.2%) had detectable levels of dust mite allergen in a bed. Approximately one half of the homes had levels at or greater than 2.0 μg/g, the proposed threshold for allergic sensitization, and approximately one quarter had levels at or greater than 10.0 μg/g, the proposed threshold for asthma.

Mean allergen levels by housing characteristics

Table I shows the median and mean (geometric) dust mite allergen concentrations for general housing unit characteristics. At the .05 level of significance, concentration was associated with construction year, census region, child resident, and household income. As the age of the homes increased, mean allergen concentration increased. The Northeast had the highest mean concentration of all

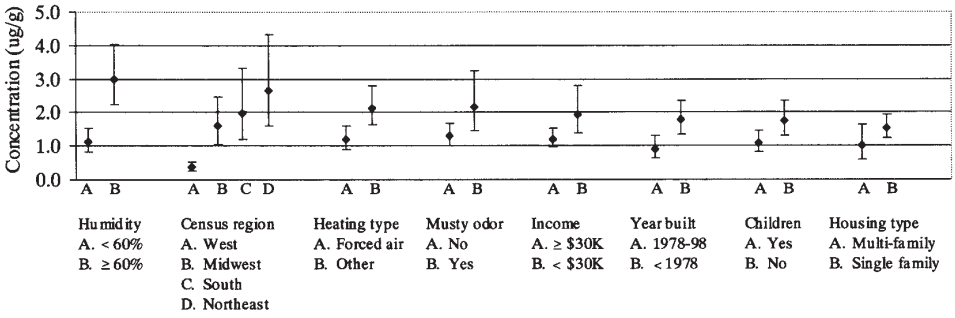

FIG 2. Mean (geometric) dust mite allergen concentrations and 95% CIs for levels of the independent predictors identified in the multivariable linear regression model.

regions, whereas the West had the lowest (a map of the 1990 census regions can be found online at http://www.census.gov/geo/www/us_regdiv.pdf). Homes without resident children had a higher mean concentration than homes with resident children. As household income decreased, allergen concentration increased. Lower educational level was associated with a higher level of dust mite allergen ($P = .056$).

Table II shows the median and mean (geometric) allergen concentrations by other characteristics that have previously been shown to be or hypothesized to be related to dust mite allergen concentration. Mean allergen concentrations were higher in homes that did not have forced-air heating, that did not use an air-filtration device, that frequently had a musty or mildew odor, and that had a dehumidifier. Mean concentration increased with each higher level of humidity. Bedrooms with evidence of moisture, such as mildew or water stains, had a much higher mean allergen concentration than bedrooms that did not have evidence of moisture; however, the P value was .10.

Independent predictors of dust mite allergen

The independent predictors of higher mean allergen concentrations identified in the multivariable linear regression were nonwestern regions ($P < .001$), higher humidity ($P < .001$), older homes ($P = .002$), frequent musty or mildew odor ($P = .01$), main heating sources other than gas or electric forced air ($P = .01$), lower household income ($P = .01$), homes without resident children ($P = .02$), and single-family homes ($P = .09$). The independent predictors of higher dust mite allergen concentration and the adjusted geometric mean concentrations for levels of the predictors are shown in Fig 2.

DISCUSSION

This is the first report of national estimates of dust mite allergen levels in US homes. This study found that 84% of US homes have detectable levels of dust mite allergen in a bed. Levels previously associated with allergic sensitization and asthma are common in US homes. Independent predictors of higher dust mite allergen concentrations were older homes, regions other than the West, single-family homes, absence of resident children, lower household income, musty or mildew odor in the home, higher bedroom humidity, and heating types other than forced air.

All predictors of increased dust mite allergen concentration, including the ones identified in the multivariable model, must be directly or indirectly related to conditions that support the propagation of dust mites, such as the presence of dust and moisture, or the persistence of the allergen, such as lack of effective cleaning. To thrive, house dust mites need food, moisture, and temperatures of between 65°F and 80°F.[19-21] Dust mites feed on the constituents of dust, such as human skin scales, animal dander, pollen, fungi, and bacteria. Dust mites absorb moisture from the air and do not proliferate at relative humidities of less than 50%.[22-24]

The strongest independent predictors of higher dust mite allergen concentrations were construction year, census region, and bedroom humidity. Other studies have reported that older homes have higher dust mite allergen levels.[25-29] In a study of homes in Sydney, Australia, it was found that the age of the home was the most significant predictor of dust mite allergen concentrations in the bed and bedroom floor.[26] It has been suggested that newer homes have lower allergen levels because they are warmer and drier, the result of more efficient insulation and central heating.[27,29] Our data suggest that older homes are dustier, thus providing a more abundant food source for dust mites. Indeed, when we compared mean bed dust sample weights by year of construction, we found that mean weights increased for each older category of construction ($P = .0003$). Relative to homes in the West, nonwestern homes had significantly higher levels of dust mite allergen. Nonwestern regions of the country are generally more humid. A study of homes in 10 Rocky Mountain states found that with the exception of homes with unusual sources of humidity, significant numbers of dust mites (<100 mites per gram of dust) were rare. Although bedroom humidity was only measured at one point in time in our study, the mean concentration of dust mite allergen increased with each incremental increase in relative humidity (Table II), which confirms the dust mite's preference for humid environments. Another indicator of moisture, a frequent musty or mildew odor in the home, was a significant predictor of higher allergen levels. These moisture-related predictors

TABLE II. Median and mean dust mite allergen concentrations (in micrograms per gram) distributed by allergen-related housing and behavioral characteristics

Characteristic	n	Median	Geometric mean (SE)	*P* value
Home's main heating source				
Gas or electric forced air	506	1.05	1.02 (0.16)	
Steam or hot water radiator	64	2.84	3.26 (1.42)	
Other (eg, space heater)	166	3.55	2.59 (0.44)	<.001
Air conditioner in the home				
Yes	582	1.18	1.27 (0.18)	
No	153	2.62	2.11 (0.77)	.22
Air-filtration device in the home*				
Yes	91	0.60	0.74 (0.24)	
No	628	1.81	1.54 (0.20)	.04
Dampness in the home in the past 12 mo				
No	493	1.34	1.40 (0.22)	
Yes	239	1.68	1.39 (0.31)	.99
Frequent musty or mildew odor in the home				
No	570	1.16	1.20 (0.17)	
Yes	154	3.94	2.70 (0.66)	.004
Dehumidifier used in the home				
No	602	1.25	1.20 (0.17)	
Yes	121	2.68	2.71 (0.61)	.003
Pets in the home				
Yes	356	1.16	1.35 (0.18)	
No	373	1.98	1.45 (0.30)	.76
Use impermeable pillow or mattress covers				
Yes	26	0.40	0.80 (0.56)	
No	702	1.59	1.41 (0.18)	.41
Bedroom floor last cleaned				
<1 wk	358	1.51	1.26 (0.20)	
≥1 wk	334	1.67	1.60 (0.34)	.36
Bedding washed within last week				
Yes	488	1.39	1.29 (0.16)	
No	203	1.28	1.47 (0.40)	.62
Wash-water temperature				
Cold	129	1.10	1.16 (0.24)	
Warm	330	1.17	1.29 (0.29)	
Hot	234	2.35	1.58 (0.44)	.65
Bedroom temperature (°F)†				
<65	30	2.81	1.90 (0.59)	
65-74	284	1.21	1.31 (0.25)	
75-84	359	1.46	1.36 (0.32)	
≥84	46	1.80	1.91 (0.85)	.73
Bedroom humidity (%)†				
<40	127	0.41	0.65 (0.15)	
40-49	235	0.83	0.83 (0.16)	
50-59	168	1.90	1.73 (0.45)	
60-69	135	3.81	3.45 (0.68)	
≥70	59	4.91	4.08 (2.26)	<.001
Carpet on bedroom floor†				
Yes (carpets, mats, area rugs)	611	1.47	1.30 (0.21)	
No	111	1.67	2.15 (0.52)	.13
Stuffed animals on the bed†				
Yes	176	1.30	1.42 (0.38)	
No	539	1.50	1.39 (0.20)	.95
Evidence of moisture in the bedroom†				
No	672	1.31	1.31 (0.19)	
Yes	58	3.21	3.34 (1.70)	.10
Season surveyed				
Winter	177	1.50	1.19 (0.27)	
Summer	255	1.65	1.50 (0.41)	
Fall	304	1.34	1.47 (0.37)	.76

*Assessed by the following question: "Do you have an air-filtration device in your home, such as a HEPA filter system, electrostatic air filter, or some other special filter?"
†Assessed by observation; all others assessed by questionnaire.

suggest that controlling indoor moisture might be an effective way to reduce dust mite allergen levels. It has been demonstrated that the lowering of indoor relative humidity through the use of a high-efficiency dehumidifier and air conditioning can result in significant reductions in dust mite numbers and allergen.[30]

Another significant predictor of lower dust mite allergen levels was the presence of forced-air heating; however, observational studies have reported conflicting results. A study of bed and bedroom floor dust in homes of 2 Canadian cities found that forced-air heating was associated with increased dust mite allergen levels.[25] The authors hypothesized that this effect might be due to increased dustiness associated with this type of heating. A study in Melbourne, Australia, found higher dust mite allergen levels in beds and bedroom floors of centrally heated homes.[29] The authors stated that this finding was probably because of centrally heated homes being less ventilated, which in turn might increase indoor humidity. Finally, a study in the United Kingdom that examined the effects of house characteristics on dust mite counts found that central heating was associated with significantly lower numbers of dust mites in mattresses.[27] Randomized intervention trials are needed to definitively determine the effects of forced-air heating on allergen levels.

Three predictors of higher allergen—lower household income, absence of a child resident, and single-family housing unit—are more difficult to explain. A study of allergen levels in homes of a northeastern US city found that bed allergen levels were 19 to 31 times greater in houses than in apartments.[31] The authors reported that apartments tended to have hotter and drier interiors than houses. Other studies are needed to determine why these characteristics are predictors of dust mite allergen.

Several behaviors in Table II that would be part of any allergen mitigation strategy were not significantly associated with allergen levels in this study. These included using impermeable mattress and pillow covers, washing the bedding weekly, using hot water to wash bedding, and not having stuffed animals on the bed, each of which was assessed by means of questionnaire. The lack of statistical significance for the use of impermeable covers likely reflects the low percentage (4%) of homes that reported their use. Although washing bedding in water hotter than 130°F has been shown to kill dust mites,[21,32] reported wash-water temperature was not related to bed allergen levels in this study. Many studies have demonstrated that the use of impermeable covers and the frequent washing of bedding and cleaning of floors or carpet are effective in reducing levels of dust mite allergens in bedrooms.[33-44]

The major limitation of this study was that the dust sampling and home observations, including temperature and relative humidity readings, were conducted at a single point in time. It has been demonstrated that concentrations of dust mite allergens vary over time and by season.[15,31,45-49] For the NSLAH I, it was not feasible to collect samples from the same homes at multiple points in time. The cross-sectional design of the NSLAH I was the most efficient design for estimating average allergen concentrations across the nation, describing the levels by housing characteristics, and identifying predictors of dust mite allergen concentration.

Another limitation was the number of missing dust mite allergen values. Of the 831 homes surveyed, 50 bed dust samples were not collected, and 45 bed samples had insufficient dust to assay for either Der f 1 or Der p 1. The most common reason for a bed sample not being collected was that field technicians were denied access to the bedroom or bed. However, a comparison of homes with and without missing dust mite allergen data for the bed indicated that they do not differ on the basis of any of the characteristics in the final prediction model.

The major strength of this study is that the NSLAH I represents approximately 96 million permanently occupied noninstitutional housing units that allow children residents. Although previous studies have reported exposure to dust mite allergens in indoor environments, these studies have not been representative of the US housing stock. The distributions of demographic and housing unit characteristics of the NSLAH I homes have been shown to be comparable with those obtained from the 1995 and 1997 American Housing Survey and the 1998 and 1999 Current Population Survey.[17]

Until there are inexpensive and practical ways for people to measure dust mite allergen levels in their homes, the results from this article can be used by clinicians and researchers to identify conditions under which homes are more likely to have increased dust mite allergen levels. Although there are things that persons can do to lower dust mite allergen levels in their homes, such as using impermeable mattress covers and washing bedding weekly in hot water, this study suggests that the construction and operation of a house might have a significant influence on the level of allergens. Future studies are needed to identify these constructional and operational aspects of homes, followed by intervention trials that clearly demonstrate a reduction in dust mite allergen levels and prevention of disease.

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