

# Socioeconomic Predictors of High Allergen Levels in Homes in the Greater Boston Area

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In the United States, childhood asthma morbidity and prevalence rates are the highest in less affluent urban minority communities. More than 80% of childhood asthmatics are allergic to one or more inhalant allergens. We evaluated whether socioeconomic status was associated with a differential in the levels and types of indoor home allergens. Dust samples for an ELISA allergen assay were collected from the homes of 499 families as part of a metropolitan Boston, Massachusetts, longitudinal birth cohort study of home allergens and asthma in children with a parental history of asthma or allergy. The proportion of homes with maximum home allergen levels in the highest category was 42% for dust mite allergen ( $\geq 10$   $\mu\text{g/g}$  Der p 1 or Der f 1), 13% for cockroach allergen ( $\geq 2$  U/g Bla g 1 or Bla g 2), 26% for cat allergen ( $\geq 8$   $\mu\text{g/g}$  Fel d 1), and 20% for dog allergen ( $\geq 10$   $\mu\text{g/g}$  Can f 1). Homes in the high-poverty area ( $> 20\%$  of the population below the poverty level) were more likely to have high cockroach allergen levels than homes in the low-poverty area [51 vs. 3%; OR, 33; 95% confidence interval (CI), 12–90], but less likely to have high levels of dust mite allergen (16 vs. 53%; OR, 0.2; CI, 0.1–0.4). Lower family income, less maternal education, and race/ethnicity (black or Hispanic vs. white) were also associated with a lower risk of high dust mite levels and a greater risk of high cockroach allergen levels. Within a single U.S. metropolitan area we found marked between-community differences in the types of allergens present in the home, but not necessarily in the overall burden of allergen exposure. *Key words:* asthma, cat, cockroach, dog, dust mite, indoor allergens, inner city. *Environ Health Perspect* 108:301–307 (2000). [Online 18 February 2000] <http://ehpnet1.niehs.nih.gov/docs/2000/108p301-307kitch/abstract.html>

Asthma prevalence has increased in recent years and prevalence, hospitalization, and mortality rates are disproportionately high among inner-city and disadvantaged populations in the United States (1–4).

Exposure to indoor allergens may contribute to the development of childhood asthma, and it has been suggested that temporal and geographic variation in exposure levels may partially account for variations in asthma prevalence and morbidity both over time and across socioeconomic and geographic boundaries (5,6).

Consistent with this hypothesis, levels of at least some indoor allergens appear to vary by geographic location and socioeconomic conditions. Although dust mite allergen is a relatively abundant allergen in many southern and eastern U.S. cities, it is apparently less so in Arizona, New Mexico, and two Canadian cities (7–9). Cockroach allergen is more common in homes of relatively low socioeconomic status (SES) than in homes of relatively high SES, whereas the opposite is true for cat allergen (10–12).

Yet questions about allergen distribution remain. For example, the importance of the dust mite as an allergen in the inner city is unclear. Although high levels of mite

allergen were apparently rare in the eastern U.S. inner-city homes of asthmatic children participating in the National Inner City Asthma Study (13), nearly 25% of the inner-city asthmatic cohort in an Atlanta, Georgia, study had high levels of mite allergen in the home (10). Additionally, few studies compare and contrast the levels of allergen in the homes of asthmatics of differing socioeconomic backgrounds within the same city. Finally, whereas some data suggest that inner-city homes from different regions of the United States may have high levels of at least some allergens, whether socioeconomically disadvantaged homes have a greater burden of indoor allergens overall is unknown.

We had the unique opportunity to examine allergen levels in the homes of asthmatic or allergic people from a wide spectrum of socioeconomic backgrounds within a single urban area, as part of a large birth cohort study of the role of allergen exposure in the development of asthma. We examined the differences in the types and levels of allergens by income, racial/ethnic backgrounds, and location of the homes within the greater Boston, Massachusetts, area.

## Materials and Methods

**Cohort.** Between September 1994 and June 1996, 499 families with a history of asthma or allergy in at least one parent were enrolled in a birth cohort study designed to examine the effects of early life allergen exposure on the development of childhood asthma. On weekdays (Monday–Friday), all mothers who delivered their babies at a large Boston hospital were approached for screening 24 to 48 hours after delivery if they lived within Route 128 (which roughly encircles the greater metropolitan area), were  $\geq 18$  years old, and were able to speak English or Spanish. Families were not screened if they were identified by the floor nurse as unlikely to be comfortable with an interview, or if the index child was premature ( $< 36$  weeks), had a major congenital anomaly, or was in the neonatal intensive care unit. Mothers were asked the following simple screening questions: Have you ever had a doctor's diagnosis of asthma, hay fever, or allergies? Has the biologic father of your child ever had a doctor's diagnosis of asthma, hay fever, or allergies? If the mothers answered yes to one or both of these questions, they were asked to complete a more detailed screening questionnaire.

Over the enrollment period, we identified 7,657 women who lived within the Route 128 area and were 18 years of age or older; 5,973 were approached and asked about maternal or paternal history of asthma or allergy. Most of the mothers (5,904) agreed to answer the simple screening questions. Of these, 1,539 had a maternal or paternal history of asthma or allergy, and 1,405 families agreed to complete a more detailed screening questionnaire. Nine hundred six of the 1,405 were excluded from the study before

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measurement of home allergen levels. The reasons for exclusion included plans to move within the next year (39% of those screened), reluctance to participate in a longitudinal study (45%), loss to follow-up (14%), and other (2%). The study was approved by the Brigham and Women's Hospital (Boston, MA) Human Research Committee.

**Questionnaires.** Home visits were conducted by trained research assistants 2–3 months after the birth of the index child. The assistants administered a detailed home characteristics questionnaire. The questionnaire included questions about parental education, family income, and characteristics of the home.

**Collection and measurement of allergen levels.** Dust samples were collected from the kitchen, living room, child's bed, and child's bedroom floor of all of the homes within the first 3 months of the index child's birth. If the child spent  $\geq 3$  hr in the parents' bed for  $\geq 3$  nights a week, a sample was also collected from the parents' bed. Participants were asked not to clean (vacuum, sweep, mop, etc.) for 3 days before the visit. A Eureka Mighty-Mite vacuum cleaner (model 3621; The Eureka Co., Bloomington, IL) was modified to collect dust in 19 × 90 mm cellulose extraction thimbles. The time spent vacuuming and the area vacuumed were standardized. Dust from the child's bed and the child's bedroom floor was collected in separate thimbles. For the child's bed sample, all layers of bedding, including the mattress surface, were vacuumed for 5 min. For the bedroom floor sample, 2 m<sup>2</sup> of the floor surrounding the bed was vacuumed for 5 min. In the living room, the 5-min vacuuming included 2 m<sup>2</sup> of the floor and an upholstered chair or seat where the child and caregiver often sat (if such a chair was identified). In the kitchen, the floor surrounding the cabinets, around the refrigerator, and under the sink was vacuumed for 5 min.

Dust samples were placed in airtight plastic bags immediately after collection, then returned to the laboratory. Within 48 hr after collection, the dust was weighed and sifted through a 425- $\mu$ m mesh sieve, and a portion of the fine dust was extracted (50 mg/mL borate-buffered saline). Extracts were stored at -20°C until analysis. Each sample was analyzed for allergens from dust mite (Der p 1 and Der f 1), cockroach (Bla g 1), and cat (Fel d 1). The Bla g 1 and Bla g 2 lower limits of detection were 0.05 U/g, the Der p 1 and Der f 1 lower limits were 0.025  $\mu$ g/g, and the Fel d 1 lower limit was 0.0125  $\mu$ g/g. When an adequate amount of living room sample was available, we also performed an assay for dog allergen (Can f 1); when an adequate amount of kitchen sample was available, we also measured a second

cockroach allergen (Bla g 2). For dust mite, cat, and dog allergens, we used two-site monoclonal antibody ELISA assays (14–16). The cockroach assay differed in that a polyclonal rabbit antibody specific for cockroach was used for antigen capture (17). All antibodies and reference allergens were obtained from M. Chapman (University of Virginia, Charlottesville, VA).

**Statistical analysis.** For the purpose of analysis, we categorized dust mite allergen levels as Der f 1 or Der p 1 at one of three levels: < 2.0  $\mu$ g/g (including assays below the limits of detection and those samples with no dust); 2–10  $\mu$ g/g; or  $\geq 10$   $\mu$ g/g. Cockroach allergen levels were categorized as Bla g 1 or Bla g 2 at one of three levels: < 0.05 U/g (including assays below the limits of detection); 0.05 to < 2 U/g; or  $\geq 2$  U/g.

We performed regression analyses for dust mite and cockroach allergen, with allergen level (greater than or equal to the specified cut point) as the dependent variable for each of the analyses. We performed two separate analyses for dust mite allergens using the cut points Der f 1 or Der p 2 at  $\geq 2$   $\mu$ g/g and Der f 1 or Der p 2 at  $\geq 10$   $\mu$ g/g, respectively. Similarly, we performed two separate analyses for cockroach allergens; the cut points were Bla g 1 or Bla g 2 at  $\geq 0.05$  U/g and Bla g 1 or Bla g 2 at  $\geq 2$  U/g. The categories for each of the allergens were based on levels that have been associated with sensitization or exacerbation or development of asthma (5,10,11,17–19). Uncertainty about such cut points or thresholds motivated us to explore two different levels for both dust mite and cockroach allergen (20,21).

The highest level of an allergen recorded from any of the four sample sites in a home was termed the maximum allergen level in the home, or home maximum. We performed the logistic regression analyses using this value for each of the homes.

We used zip-code boundaries to define areas within the greater Boston vicinity. The percent of the population below the poverty level was determined for each of the zip-code areas based on data from the 1990 U.S. Census (U.S. Census Bureau, Suitland, MD). The zip-code areas were then combined to form three poverty area categories: low ( $\leq 5\%$  of individuals below the poverty level), medium ( $> 5$ – $20\%$  of individuals below the poverty level), and high ( $> 20\%$  of individuals below the poverty level). The poverty level data were based on data from the 1990 U.S. Census.

Household race/ethnicity was assigned based on the race/ethnicity designation of the parents. If either of the parents considered him- or herself black, the household was designated as black. In the absence of a black parent, if either parent considered him- or

herself Hispanic, the household was designated as Hispanic. Similarly, in the absence of a black or Hispanic parent, if either parent considered him- or herself Asian, the household was designated as Asian. The household was designated white if neither parent considered him- or herself black, Hispanic, Asian, or other.

Family income was categorized as  $\geq$  \$50,000, \$30,000 to < 50,000, or < \$30,000. We categorized education on the basis of maternal education; education categories were postcollege, college, or high school or less.

The home characteristic categories have been previously described (22). Briefly, the type of home was grouped into buildings with three or more apartments versus houses and duplexes. Seasons were categorized as winter (November–February), spring (March–May), summer (June–August), and fall (September–October). The type of floor covering was defined as smooth or carpeted and was based on a field technician's observation.

We examined each of the following variables for association with allergen levels: poverty area, maternal education, family income, race/ethnicity, type of home (single family or multiapartment), and season of sampling. Analyses were performed with chi-square and simple logistic regression. For the logistic regression analyses, we used the binary outcome allergen level in the (moderate or high) category (yes or no) for each of the allergens as the dependent variables. For the cockroach, we considered the allergen present in the high category if either Bla g 1 or Bla g 2 were present above the cut point. Similarly, for the dust mite, we considered the allergen present in the high category if either Der p 1 or Der f 1 were present above the cut point. Independent variables were dummy-coded, and in each case the largest group was the baseline. We performed multivariable analysis using multiple logistic regression.

## Results

**Population characteristics.** There were 499 families in the final cohort, all of whom lived in the greater Boston area. Characteristics of the enrolled study population are given in Table 1. As compared to those classified as living in low-poverty areas, families classified as living in high-poverty areas were significantly more likely to have a family income < \$30,000 and were more likely to be black or Hispanic, as shown in Table 2. Homes located in the high-poverty areas were also more likely to be in multiapartment buildings (three or more apartments in a single building).

**Allergen levels.** Of the homes assayed, 42% (213) had dust mite allergen levels in the highest category (Der p 1 or Der f 1,

≥ 10 µg/g) and 13% (66) had cockroach allergen levels in the highest category (Bla g 1 or Bla g 2, ≥ 2 U/g). Results are shown in Table 3 and Figure 1.

Der f 1 was more commonly present at high levels than Der p 1. Der f 1 levels were in the highest category in 40% of the homes, whereas Der p 1 levels were in the highest category in only 11% of the homes. Overall, 67% of the homes had Der f 1 or Der p 1 levels ≥ 2 µg/g, 67% had Fel d 1 levels ≥ 1.0 µg/g, and 60% had Bla g 1 or Bla g 2 levels ≥ 0.05 U/g.

**Poverty area, socioeconomic, and racial/ethnic risk factors for moderate or high allergen levels.** Poverty area (Figure 2) was associated with the type and level of allergen exposure (Figure 1 and Tables 4 and 5). Living in the high-poverty region of the Boston area was associated with an increased risk of moderate or high levels of cockroach allergen and, conversely, a decreased risk of moderate or high levels of dust mite allergen. These associations were present in each of the rooms sampled and at two cut points for both allergens. An exception to these associations was dust mite allergen in the kitchen; there was a low prevalence of moderate or high levels of allergen in the kitchen in all of the poverty areas. In univariate logistic regression analysis, dust mite and cockroach allergen levels also varied by family income and race/ethnicity (Tables 4 and 5).

Overall, although 53% of the homes in the low-poverty areas had dust mite allergen levels ≥ 10 µg, only 16% of the homes in the high-poverty areas had levels ≥ 10 µg (*p*-value < 0.001). Approximately 50% of white households and about 20% of the black households had mite allergen levels in the highest category (≥ 10 µg). Similarly, dust mite levels in the moderate or highest categories were more common among those with higher family incomes and those with greater maternal education.

Conversely, homes in the high-poverty area were more likely to have high cockroach allergen levels (≥ 2 U/g) than homes in the low-poverty area (51 vs. 3%; *p*-value < 0.001). Approximately 52% of the black homes and 40% of the Hispanic homes had cockroach levels in the highest category (≥ 2 U/g), as compared to 5% of the white and 7% of the Asian homes. Family income and maternal education, both of which were associated with race/ethnicity and location in our population, showed the same pattern: those households with lower family income and less maternal education were also at greater risk for high cockroach allergen levels.

Living in the low- or mid-poverty areas and classification as white or Asian were each associated with increased risk of cat allergen levels in the high category. Approximately

24% of the homes in the low-poverty area had levels in the highest category, as compared to 11% in the high-poverty area. Nearly 50% of Asian households and 27% of white households had Fel d 1 levels in the highest category, as compared to 8% of the black households (*p* < 0.05).

High levels of dog allergen were more evenly distributed between the poverty level areas than cat allergen; 18% of the high-poverty area, 18% of the mid-poverty area, and 23% of the low-poverty area homes had Can f 1 levels ≥ 10 µg/g. Levels of dog allergen varied substantially by race/ethnicity, however; 4% of Hispanic homes, 9% of black homes, 17% of Asian homes, and 23% of white homes had levels ≥ 10 µg/g.

Consistent with the associations noted for allergen levels, having a cat or dog in the home was less common among those living in the high-poverty areas, in black or Hispanic households, or in those with the lowest family income. One or more cats were allowed in the homes of 4% (2 of 45) of those who lived in the high-poverty area, as compared to 16% (31 of 195) of those living in the low-poverty area. Dogs were slightly less common in high-poverty areas than in low-poverty areas (13 vs. 19%). As shown elsewhere (22), nearly all (96 of 98, or 98%) of those homes in which a cat was allowed inside the home had an Fel d 1 level ≥ 8 µg/g, as compared to 35 of 399 (8.7%) of those without a cat. A similar relationship between the presence of an animal and a high level of allergen in the home was seen for dogs; 64 of 67 (95.5%) of those with a dog allowed in the home had Can F1 levels ≥ 10 as compared to 18 of 354 (5.2%) of those without.

**Table 1.** General characteristics of family cohort (total *n* = 499).

Characteristic	No.	Percent
Area of residence		
Low poverty	195	39
Medium poverty	259	52
High poverty	45	9
Maternal education		
Post college	231	46
College	159	32
High school or less	109	22
Family income		
≥ \$50,000	348	70
\$30,000 to < 50,000	88	18
< \$30,000	48	10
Insurance		
Private	463	93
Medicaid	26	5
No insurance	9	2
Race/ethnicity		
White	370	74
Black	64	13
Hispanic	30	6
Asian	28	6
Other	7	1

**Socioeconomic predictors of dust mite and cockroach allergen, adjusting for home characteristics.** Chew et al. (22) reported that the type of home, the type of floor covering, and the season of sampling are associated with dust mite levels in our study homes. As compared to apartments, houses were twice as likely to have high levels of dust mite allergen. Homes with carpeted floors or those that were sampled in the summer were also more likely to have high levels of dust mite whether ≥ 2 µg/g or ≥ 10 µg/g was used as the cut point, although homes without these characteristics frequently had high levels (22).

In the present analysis, these home characteristics only partially accounted for the associations between the various SES indicators of disadvantage and lower dust mite levels. Frequency of room vacuuming, a weak univariate predictor of dust mite levels, did not influence associations between SES and dust mite allergens. Similarly, the type of home and the season of sampling only partially explained the associations between SES and cockroach allergens, which remained significant after controlling for these home characteristics. For example, the odds ratio for dust mite ≥ 10 µg/g for homes in the areas with high-poverty rates versus the areas

**Table 2.** Relationship between family income, race/ethnicity, and poverty area.

Characteristic	Poverty area		
	Low no. (%)	Medium no. (%)	High no. (%)
Family income			
≥ \$50,000	173 (90)	164 (63)	11 (25)
\$30,000 to < 50,000	17 (9)	60 (23)	11 (25)
< \$30,000	1 (1)	26 (10)	21 (48)
Race/ethnicity			
White	170 (87)	190 (73)	10 (22)
Black	1 (< 1)	35 (14)	28 (62)
Hispanic	6 (3)	17 (7)	7 (16)
Asian	13 (7)	15 (6)	0 (0)
Other	5 (3)	2 (1)	0 (0)

**Table 3.** Overall prevalence of allergens by maximum allergen level in the home.

Allergen	No.	Percent
Der p 1 or Der f 1 (µg/g)	498	
≥ 10	213	42
2 to < 10	120	24
< 2	166	33
Bla g 1 or Bla g 2 (U/g)	499	
≥ 2	66	13
0.05 to < 2	232	47
< 0.05	201	40
Fel d 1 (µg/g)	498	
≥ 8	131	26
1 to < 8	204	41
< 1	163	33
Can f 1 (µg/g)	412	
≥ 10	82	20
< 10	330	80

with low-poverty rates changed from 0.2 to 0.3; the odds ratio for cockroach allergen  $\geq 2$  U/g for homes in the areas with high-poverty rates versus the areas with low-poverty rates changed from 33 to 18.

In multivariable models adjusting for other SES variables as well as home characteristics, the level of area poverty appears to explain some of the differences in both dust mite and cockroach allergen levels, although for both allergens the significance of the relationships varies with the cut point used (Tables 4 and 5). Family income was not a significant independent predictor of dust mite

allergen after adjustment for home characteristics and race/ethnicity, and was therefore not included in the final model for dust mite.

High-poverty areas were at lower risk of dust mite exposure for both cut points, although the association was not significant when we used a cut point of  $\geq 2$   $\mu\text{g/g}$ . Area poverty was the most important risk factor for having any detectable cockroach allergen, whereas family income was more strongly associated with the risk of high levels of cockroach allergen. Colinearity issues and sample size limit interpretation of models containing all SES and home characteristics

variables, although race/ethnicity appeared to have significant associations with dust mite and cockroach levels that were independent of the other SES and home characteristics variables considered.

## Discussion

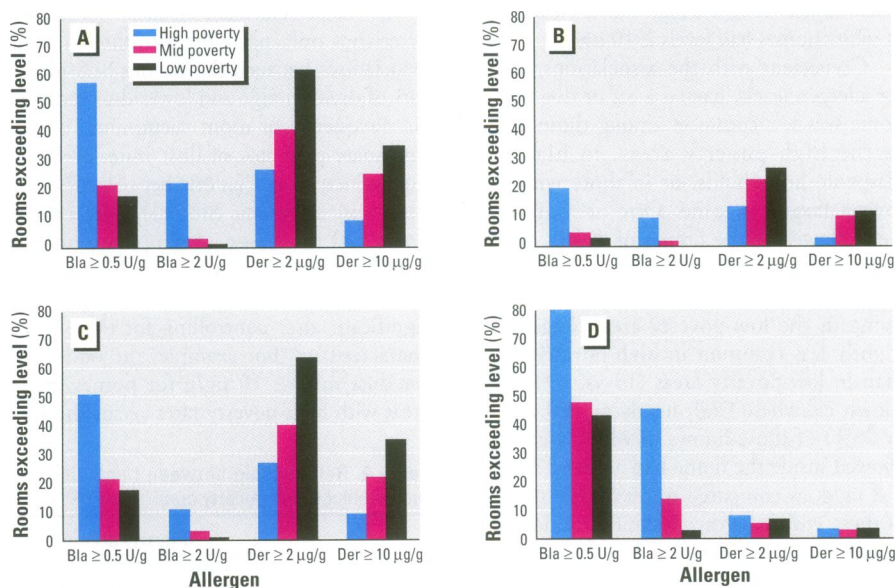
We found that homes in the high-poverty regions of a large metropolitan area were more likely to have high levels of cockroach allergen and, conversely, less likely to have high levels of dust mite or cat allergens. Variation in allergen levels was also associated with family income and race/ethnicity.

The strengths of our study include the measurement of multiple allergens, the collection of dust from multiple sites in all of the homes, and the sampling of a large number of homes. We also sampled homes from different residential areas or regions (which we designated as poverty areas) within a single metropolitan area, and the homes of families with different racial and socioeconomic backgrounds, allowing us to study the determinants of within-city between-group variation in allergen type and level.

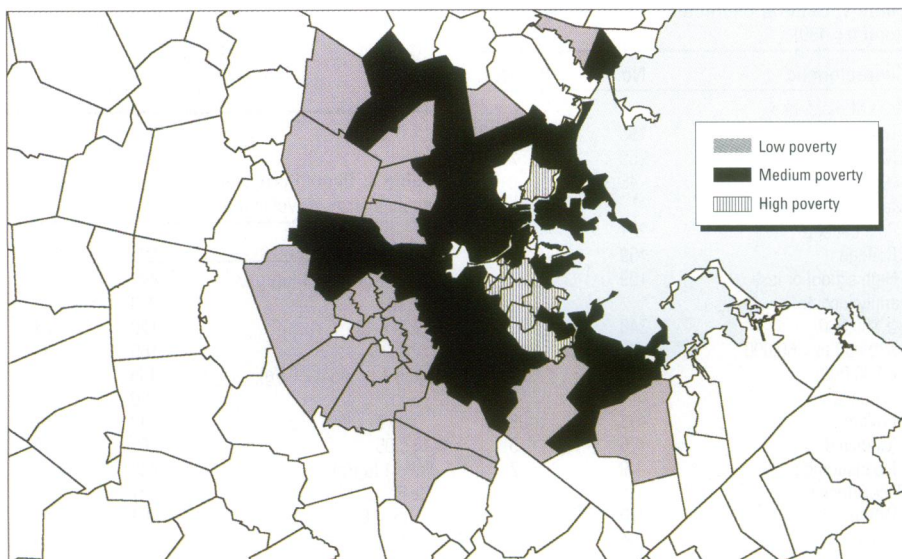
Other studies have shown that cockroach allergen levels tend to be highest in inner-city, in certain minority, and in lower income homes (10–12). Substandard housing and multiunit buildings, which are generally more common in the inner city, are thought to promote cockroach infestation and thus contribute to the high allergen levels (23). In our study population, those who lived in high-poverty areas were considerably more likely to live in multiapartment buildings (three or more apartments in a single building) than those who lived in low-poverty areas (58% of the high-poverty area vs. 4% of the low-poverty area).

Other studies have also demonstrated that cat allergen levels vary by location within a city, by race/ethnicity, and by socioeconomic status (10,11). In our population, those who lived in the high-poverty areas were less likely to keep cats as pets, and it follows that they would be less likely to have cat allergen levels in the highest category. Although Fel d 1 has been found in dust samples of homes both with and without cats, the presence of allergen levels  $\geq 8$   $\mu\text{g/g}$  is strongly associated with the presence of a cat (22).

Significantly, in our Boston cohort we found that dust mite levels also vary within a single city by poverty area, by race/ethnicity, and by income variables. Previous studies of dust mite levels in the urban setting have produced varied results. The National Inner City Asthma Study (13) reported a lower prevalence of high levels of dust mite among inner-city homes than in our study (10% of homes had levels  $\geq 2$   $\mu\text{g/g}$ , vs. 42% in our study). A study of 57 homes in Atlanta by



**Figure 1.** Prevalence of moderate or high levels of dust mite or cockroach allergen for (A) child's bedroom floor, (B) child's bed, (C) living room, and (D) kitchen, by poverty area. Low poverty was defined as  $\leq 5\%$  of individuals below the poverty level based on 1990 U.S. Census data; mid poverty was defined as  $> 5\text{--}20\%$  of individuals below the poverty level; and high poverty was defined as  $> 20\%$  of individuals below the poverty level.



**Figure 2.** Map of the Boston area showing the distribution of poverty areas in our cohort. Scale: 1 inch equals approximately 4.5 miles.

Call et al. (10) and a study of 186 homes in Wilmington, Delaware, by Gelber et al. (11) reported much higher prevalences of high levels of dust mite allergen in inner-city homes (~ 25% had levels  $\geq 10 \mu\text{g/g}$ ) than either our study or the National Inner City Asthma Study (13). Of these other studies only the Wilmington study examined both urban and suburban homes; levels were similar between the two areas. The absence of a difference in dust mite levels between poverty areas in Wilmington, which contrasts with our results, may be a function of the geographic location of the cities studied and/or a function of differences in heating systems and indoor humidity.

We believe that differences in home characteristics and housing stock are responsible for the within-metropolitan-area socioeconomic and race/ethnicity gradients in dust mite and cockroach levels that we observed (8,22,24,25). The home characteristics, which we measured and reported elsewhere (22) as predictors of dust mite allergens (the type of building, the type of floor covering, and the season) and cockroach allergens (the type of building and the season), only partially explained these socioeconomic gradients in

allergen levels. Unmeasured characteristics (e.g., winter indoor temperature, better measures of indoor humidity, or additional details on home condition) may account for the unexplained aspect of the observed differences. For example, other investigators have suggested that certain homes may have higher air exchange rates and may therefore be drier (26,27). Although we did not find a difference in humidity between different home types, our measurements were made during a single home visit, and may not reflect household averages or microenvironmental relative humidity.

We also found that black and Hispanic race/ethnicity are independently associated with reduced dust mite levels. Sarpong et al. (12) showed that African American race is an independent predictor of cockroach exposure. As has been suggested for cockroach allergens, it seems likely that differences in home characteristics and housing stock explain the differences in dust mite allergen levels attributable to race/ethnicity. The inability of home characteristics to fully account for the effect of race/ethnicity in our multivariate analysis suggests important unmeasured characteristics.

In our cohort, Der f 1 was more prevalent than Der p 1, which was expected because other studies have shown that the dust mite species *Dermatophagoides farinae* is more common in the cooler, less humid northern climates than *Dermatophagoides pteronyssinus* (8).

Some researchers have postulated that the increased burden of asthma experienced by inner-city and low-income groups is at least partly attributable to a greater burden of allergen exposure among poor inner-city minority populations (2,28). Although this may still prove true, our study showed that not all allergen levels are higher in the high-poverty areas. Though homes in high-poverty areas were more likely to have high levels of cockroach allergen, they were less likely to have high dust mite and cat allergen levels. As a result, the risk of having at least one allergen level in the highest category did not vary significantly by area of residence (69% of the high-poverty area vs. 71% of the low-poverty area homes). We did find that those in the lowest income group, all of whom lived in high-poverty areas, had a greater risk of having at least one allergen level in the highest category.

**Table 4.** Estimates of associations between socioeconomic factors and maximum level of Der p 1 or Der f 1 in the home, shown as OR (95% confidence limit).

Variable	$\geq 2 \mu\text{g/g}$ Der p 1 or Der f 1				$\geq 10 \mu\text{g/g}$ Der p 1 or Der f 1			
	Model 1 <sup>a</sup>	Model 2	Model 3	Model 4 <sup>b</sup>	Model 1 <sup>a</sup>	Model 2	Model 3	Model 4 <sup>b</sup>
Family income								
$\geq \$50,000$	1	–	–	–	1.0	–	–	–
\$30,000 to < \$50,000	0.7 (0.4, 1.1)	–	–	–	0.8 (0.5, 1.3)	–	–	–
< \$30,000	0.3 (0.2, 0.5)	–	–	–	0.3 (0.1, 0.6)	–	–	–
Area poverty								
Low	–	1.0	–	1.0	–	1.0	–	1.0
Medium	–	0.4 (0.3, 0.6)	–	0.6 (0.4, 1.0)	–	0.6 (0.4, 0.8)	–	0.7 (0.5, 1.1)
High	–	0.2 (0.1, 0.4)	–	0.6 (0.3, 1.5)	–	0.2 (0.1, 0.4)	–	0.4 (0.1, 1.0)
Race/ethnicity								
White	–	–	1.0	1.0	–	–	1.0	1.0
Asian	–	–	0.7 (0.3, 1.6)	0.9 (0.4, 2.1)	–	–	0.8 (0.4, 1.7)	0.9 (0.4, 1.9)
Black	–	–	0.2 (0.1, 0.4)	0.4 (0.2, 0.7)	–	–	0.3 (0.1, 0.5)	0.5 (0.2, 1.1)
Hispanic	–	–	0.1 (0.1, 0.3)	0.2 (0.1, 0.5)	–	–	0.1 (0.1, 0.4)	0.2 (0.1, 0.6)

<sup>a</sup>Models 1–3 are univariate logistic regression analyses with the variables for family income, area poverty, and race/ethnicity as the independent variables, respectively. <sup>b</sup>Model 4 is a multivariate model containing the variables for home characteristics (season of sampling and house/duplex vs. apartment), area poverty, and race/ethnicity.

**Table 5.** Estimates of associations between socioeconomic factors and maximum level of Bla g 1 or Bla g 2 in the home, shown as OR (95% confidence limit).

Variable	$\geq 0.05 \text{ U/g}$ Bla g 1 or Bla g 2				$\geq 2 \text{ U/g}$ Bla g 1 or Bla g 2			
	Model 1 <sup>a</sup>	Model 2	Model 3	Model 4 <sup>b</sup>	Model 1 <sup>a</sup>	Model 2	Model 3	Model 4 <sup>b</sup>
Family income								
$\geq \$50,000$	1.0	–	–	1.0	1.0	–	–	1.0
\$30,000 to < \$50,000	1.2 (0.8, 2.0)	–	–	0.9 (0.5, 1.5)	3.4 (1.6, 6.9)	–	–	1.5 (0.7, 3.5)
< \$30,000	3.5 (1.6, 7.4)	–	–	1.8 (0.7, 4.5)	21.1 (10.2, 43.6)	–	–	4.9 (1.9, 12.9)
Area poverty								
Low	–	1.0	–	1.0	–	1.0	–	1.0
Medium	–	1.2 (0.8, 1.7)	–	1.0 (0.6, 1.5)	–	5.3 (2.2, 12.7)	–	1.9 (0.7, 5.3)
High	–	8.6 (3.0, 25)	–	4.2 (1.3, 14.0)	–	32.9 (12.1, 89.6)	–	2.3 (0.6, 8.9)
Race/ethnicity								
White	–	–	1.0	1.0	–	–	1.0	1.0
Asian	–	–	1.3 (0.6, 2.8)	1.4 (0.6, 3.2)	–	–	1.4 (0.3, 6.4)	1.4 (0.3, 6.7)
Black	–	–	5.0 (2.4, 10.6)	3.7 (1.6, 8.8)	–	–	19.7 (10, 38.6)	7.7 (3.2, 18.4)
Hispanic	–	–	1.7 (0.8, 3.7)	0.9 (0.3, 2.3)	–	–	12.3 (5.2, 29.2)	5.6 (1.9, 16.6)

<sup>a</sup>Models 1–3 are univariate logistic regression analyses with the variables for family income, area poverty, and race/ethnicity as the independent variables, respectively. <sup>b</sup>Model 4 is a multivariate model containing the variables for home characteristics (season of sampling and house/duplex vs. apartment), family income, area poverty, and race/ethnicity.

Whether equivalent risk is imposed by each of these allergens is not known, and this should lead to caution in comparing the burden of allergen exposure across groups. Asthmatic patients who are sensitive to cockroach allergens may have particularly high levels of IgE, more chronic and perennial symptoms, and greater disease severity (13,29). Whether cockroach allergen plays a greater role than dust mite or cat allergens in the development of asthma remains to be determined. Additionally, indoor allergens that are not yet routinely measured, such as those derived from rat or mouse, may be important in the development or morbidity of the disease. Nearly 21% of our cohort reported having seen signs of rats or mice in the home over the past year.

Just as dust mite levels were lower but not undetectable in poorer homes, cockroach levels were lower but not undetectable in more affluent homes. Although a low proportion of high-income homes had cockroach antigen levels  $\geq 2$  U/g, 50% of those with incomes  $\geq$  \$50,000 had cockroach levels  $\geq 0.05$  but  $< 2$  U/g.

Our study has several limitations. First, we measured allergen levels in settled rather than airborne dust samples. Allergen exposure itself will likely vary for a given settled dust concentration with the activity level of subjects, air exchange characteristics of the home, etc. The amount of allergen in settled dust, however, is a substantial determinant of exposure, and when sampling of levels is infrequent, settled dust concentration is conceivably a better index of concentration than aerosolized levels. This is particularly the case for dust mite and cockroach allergens, which are only transiently airborne. Moreover, the availability of airborne allergen measurements is unlikely to have changed the ranking of households in terms of allergen level or the relationship between SES and the level of allergen in the home.

Second, our variables for race/ethnicity, indicators of SES, and poverty were associated with one another, potentially interfering with multivariate analysis. In the multivariate model predicting dust mite allergens, we now include only area poverty and race, excluding income, which is not a significant predictor of dust mite after adjusting for race and family income. The confidence intervals in the adjusted analyses are widened as compared to those in the crude analyses, and although this may partly represent the effects of correlation, it also reflects the relatively small numbers in our lower SES categories.

We found, as have others, that allergen levels varied substantially from room to room within a given home (10,11,17). Regardless of the room sampled, however,

dust mite allergen levels tended to be lower and cockroach levels higher in the lower SES (high-poverty) areas. The only exception was the kitchen, where dust mite levels were low in most homes. A separate but important question is whether exposure in the home is best characterized by the allergen level in the child's bedroom, the highest level in the home, or some average of all of the rooms. The answer to this question is likely to vary with age and activity patterns of the child and family. These issues have been explored in more detail in analyses of allergen levels as predictors of health outcomes (30).

The levels of allergen necessary to induce sensitization are uncertain for each of the allergens studied. Although one prospective study of dust mite exposure found a substantially increased risk for asthma among children exposed to  $\geq 10$   $\mu$ g/g Der p 1 (5), other studies showed that sensitization may occur with exposure to considerably lower levels (20,21). With this in mind we examined two cut points for both dust mite and cockroach allergens and demonstrated a relationship between SES and allergen level at both moderate and high levels.

Finally, our study was not designed to be a random sample of the population in the greater Boston area; we selected for a stable population with a parental history of asthma or allergy and an interest in a longitudinal study. Our findings of socioeconomic gradients in allergen levels have the most relevance to the Northeastern U.S. pediatric populations most at risk for asthma. They have internal relevance as our longitudinal study begins to examine whether allergen type or total allergen burden is predictive of asthma incidence in children at risk for asthma because of family history. Assessment of the distribution of allergens by SES in a general population would require a different sampling strategy based on both SES and housing stock.

In summary, we have shown that allergen types and levels vary substantially by area of residence, family income, and race/ethnicity. However, the net allergen burden faced by inner-city and suburban residents may be more similar than previously suspected. The implications of these findings for asthma risk in vulnerable populations such as the children in our cohort is as yet unknown.

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