Allergen Sensitization Profiles in a Population-Based Cohort of Children Hospitalized for Asthma

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Abstract

Rationale: Allergen sensitization is associated with asthma morbidity. A better understanding of allergen sensitization patterns among children hospitalized for asthma could help clinicians tailor care more effectively. To our knowledge, however, sensitization profiles among children hospitalized for asthma are unknown.

Objectives: We sought to describe allergen sensitization profiles and the distribution of self-reported in-home exposures among children hospitalized for asthma. We also sought to assess how sensitization profiles varied by sociodemographic and clinical factors.

Methods: This population-based cohort study includes data for 478 children, aged 4–16 years, hospitalized for an asthma exacerbation. Predictors included child age, race, sex, insurance status, reported income, salivary cotinine, exposure to traffic-related air pollution, asthma and atopic history, and season of admission. Outcomes included serum IgE specific to *Alternaria alternata*/*A. tenuis*, *Aspergillus fumigatus*, American cockroach, mouse epithelium, dust mite (*Dermatophagoides pteronyssinus* and *farinae*), cat dander, and dog dander (deemed sensitive if IgE $\geq$ 0.35). Self-reported adverse exposures included mold/mildew, water leaks, cockroaches, rodents, and cracks or holes in the walls or ceiling. Presence of carpeting and furry pets was also assessed.

Measurements and Main Results: More than 50% of included patients were sensitized to each of *Alternaria*, *Aspergillus*, dust mite, cat dander, and dog dander; 28% were sensitized to cockroach and 18% to mouse. Roughly 68% were sensitized to three or more allergens with evidence of clustering. African American children, compared with white children, were more likely to be sensitized to *Alternaria*, *Aspergillus*, cockroach, and dust mite (all $P < 0.01$). White children were more likely to be sensitized to mouse, cat, and dog (all $P < 0.01$). Lower income was associated with cockroach sensitization whereas higher income was associated with dog and cat sensitization (all $P < 0.01$). Atopic history was associated with sensitization to three or more allergens ($P < 0.01$). Although 42% reported exposure to at least one adverse in-home exposure (and 72% to carpet, 51% to furry pets), only weak relationships were seen between reported exposures and sensitizations.

Conclusions: Most children admitted to the hospital for asthma exacerbations are sensitized to multiple indoor allergens. Atopy on the inpatient unit serves as a potential target for improvement in chronic asthma management.

Keywords: asthma; allergen sensitization; environment; hospitalizations; pediatrics

(Received in original form August 15, 2014; accepted in final form January 3, 2015)

Supported by NIH 1R01AI88116 (as part of the Greater Cincinnati Asthma Risks Study) (principal investigator, R.S.K.; coinvestigators, A.F.B., B.H., C.M.K., T.W.G.). Use of REDCap was supported by the Center for Clinical and Translational Science and Training (NCRR/NIH UL1-RR026314-01). A.F.B. also received funding through the Cincinnati Children's Research Foundation Procter Scholar Award and NIH 1K23AI112916. Funders played no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication. This paper is subject to the NIH Public Access Policy (http://publicaccess.nih.gov).

Author Contributions: A.F.B. conceptualized and designed the study, performed the initial analysis, drafted the initial manuscript, revised the manuscripts, and approved the final manuscript as submitted. B.H. advised the initial study analysis, performed subsequent analyses, reviewed and revised the manuscript, and approved the final manuscript as submitted. C.M.K., T.W.G., and M.B.L. advised the initial study analysis, reviewed and revised the manuscript, and approved the final manuscript as submitted. D.J.M. performed study analyses, reviewed and revised the manuscript, and approved the final manuscript as submitted. R.S.K. conceptualized and designed the study, supervised data collection, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

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Ann Am Thorac Soc Vol 12, No 3, pp 376–384, Mar 2015

DOI: 10.1513/AnnalsATS.201408-376OC
Internet address: www.atsjournals.org

Asthma, a leading cause of childhood morbidity, disproportionately impacts children of minority race and low socioeconomic status (1–6). One possible contributor to observed disparities is the link between asthma and the physical environment, mediated by allergen sensitization and exposure (7–11). Studies have demonstrated a strong connection between allergies and asthma-related health service use (12–14), symptom days (15), and suboptimal lung functioning (16). By understanding patterns of allergen sensitization, clinicians and public health officials may be more able to direct resources to those most likely to benefit.

Allergen sensitization is common among inner-city children with asthma, often as an extension or correlate of exposure to substandard housing (17–19). Skin prick testing for 14 common indoor and outdoor allergens, completed as part of the National Cooperative Inner-City Asthma Study with children aged 4–9 years recruited from emergency departments and inner-city clinics, demonstrated that 77% had at least one positive skin test and 47% had at least three (20). Others have shown that 45% of inner-city children with moderate to severe asthma are exposed to mold and 50% to cockroaches (15, 21). Routine allergy testing (22), medication changes or addition of allergen-specific immunotherapy (23, 24), and public health interventions to assess in-home allergen exposure and reduce or remediate exposures that are found all have the potential to reduce asthma morbidity among high-risk patients (25–27).

To our knowledge, however, there has been no characterization of allergen sensitization and family-reported exposures among children hospitalized with asthma. A broader understanding of allergen profiles within this high-morbidity population would be especially relevant as treatments, referrals, and postdischarge planning could be targeted to potentially remediable factors. Therefore, we sought to describe allergen sensitization profiles and self-reported indoor exposures among children hospitalized with asthma. We also sought to assess how these profiles varied by sociodemographic and clinical factors.

Methods

Study Design and Population

This work involved children hospitalized with asthma and enrolled in a population-based, prospective, observational cohort study conducted at the Cincinnati Children's Hospital Medical Center (CCHMC, Cincinnati, OH), a large, urban, academic pediatric facility. Patients were recruited and enrolled in the Greater Cincinnati Asthma Risks Study (GCARS) between August 2010 and October 2011 according to previously described procedures (6). Briefly, patients aged 1–16 years were identified during a hospitalization by the admitting physician's use of the evidence-based clinical pathway for acute asthma or bronchodilator-responsive wheezing. Children were excluded if they were removed from the pathway before discharge, had significant nonasthma respiratory or cardiovascular disease, resided outside of the CCHMC eight-county primary service area, or if their primary caregiver did not understand written or spoken English (approximately 2% of otherwise eligible).

Study recruitment took place, on average, 7 days/week and 12 hours/day; 774 children were successfully enrolled (62.9% of those eligible with staff available to recruit). Given that approximately 85% of child asthma hospitalizations within our primary service area occur at CCHMC facilities, the accrued sample was considered population-based (28, 29). For the study presented here, the GCARS sample was limited to children 4 years of age and older, resulting in a sample of 478 so as to allow for sensitization to inhaled allergens to occur and stabilize (30). The CCHMC Institutional Review Board approved this study.

Outcome and Predictors

The primary outcomes were sensitization to common indoor allergens, assessed using ImmunoCap (ARUP, Salt Lake City, UT), a measure of allergen-specific serum IgE. Although both serum and skin prick testing have similar diagnostic properties, serum was thought to be more appropriate to the acute, inpatient setting given skin prick testing's potential side effect of wheeze. Also, patients had not been previously asked to withhold antihistamine use, which can interfere with skin prick results (22). Allergens tested included *Alternaria alternata*/*A. tenuis*, *Aspergillus fumigatus*, American cockroach, mouse epithelium, *Dermatophagoides pteronyssinus*, *Dermatophagoides farinae*, cat dander, and dog dander. Per convention, tests were considered positive when IgE was at least 0.35 kU/L.

Secondary outcomes included self-reported in-home environmental exposures. A face-to-face survey between study personnel and the patient's caregiver included questions about household environmental conditions linked to both allergen sensitization and asthma morbidity. Caregivers were asked about adverse housing conditions: presence of mold or mildew, water leaks, cockroaches, rodents, and cracks or holes in the walls or ceiling. Caregivers were also asked about wall-to-wall carpeting and furry pets (31).

Predictors included child age, race, sex, insurance status, and reported household income. We also assessed salivary cotinine; exposure to carbon attributable to traffic (ECAT), which was used as a marker of traffic-related air pollution (32, 33); asthma and atopic history; and season of admission. Patient race was defined according to caregiver report: white/Caucasian; black/African American; Asian/Oriental; or Pacific Islander, American Indian, or Alaskan Native; or other. Ethnicity was characterized as Hispanic/non-Hispanic. For this study, racial categories were collapsed to African American, white, and multiracial/other. Children identified as Hispanic were included in the multiracial/other category. Reported income was collected as a categorical variable, ranging from less than $15,000 to $90,000 or more per year. Cotinine levels were collected via salivary sampling during the admission and defined as above or below the level of detection (34). ECAT was estimated with a land-use regression model using the home address at the time of admission (32, 33). It was dichotomized at the sample median. Caregivers were also asked whether the child was prescribed (or taking) any asthma-related medicines other than albuterol at the time of admission.

Asthma history was further characterized by caregiver report of asthma-related hospitalization, emergency or urgent care visit, or systemic steroid prescriptions in the previous year (each categorized as 0, 1, or $\geq$2). Asthma-related rehospitalization within 12 months of the index hospitalization was also identified. Severity of the index hospitalization was determined by the need for admission to the intensive care unit. History of atopy was

assessed by asking whether the child had previously been diagnosed with allergic rhinitis or eczema. Season of index admission was also identified.

Statistical Analyses

We assessed the distribution of sociodemographic variables, salivary cotinine, ECAT, asthma history and rehospitalization, history of atopy, and season of index hospitalization. Next, we assessed the frequency with which children were sensitized to each of the eight included allergens and for the number sensitized to zero, one, two, and three or more allergens. For this aggregate measure, we treated dust mite as a single entity. Thus, if a child was sensitized to either *D. pteronyssinus*, *D. farinae*, or both, they were treated as having just one sensitization. We also assessed the frequency of self-reported adverse in-home exposures, focusing first on mold or mildew, water leaks, cockroaches, rodents, and cracks or holes, and the total number of reported adverse exposures (0, 1, 2, $\geqslant$3). Reported wall-to-wall carpet and furry pets were assessed as present or absent; however, they were not included in the aggregate measure of adverse exposures.

Bivariate analyses assessed the degree to which allergen sensitizations differed by potential predictors. Here, relationship significance was judged using either the chi square test or the Mantel–Haenszel test of trend. Analyses were performed with SAS software (Cary, NC).

We expected that sensitizations and exposures would aggregate in ways that were not random. Thus, in an attempt to more clearly depict allergen and exposure clustering, we performed a network analysis. To do this, we converted a binary (patient by variable) mode to a single mode (variable by variable) or 15×15 frequency matrix (including each of the 8 allergen and 7 exposure variables). In network analyses, there are multiple options for positioning the variables; here, multidimensional scaling was used to compute an x, y coordinate for each variable. The likelihood of co-occurrence was depicted by closer proximity of points. To determine how often variables co-occurred, frequency values were converted to quartiles (higher co-occurrence frequency = higher quartile). Frequency of co-occurrence was depicted by the thickness of ties between variables—thicker lines indicated higher quartile of co-occurrence. Multidimensional scaling analyses were performed with R statistical software (R Foundation for Statistical Computing, Vienna, Austria); network alyses were performed with UCINET (Analytic Technologies, Lexington, KY).

Results

A total of 478 children were included. This sample was 61% African American, 70% publicly insured, and 67% male with a median age of 8.0 years (Table 1). A total of 33% reported annual income less than $15,000. In addition, we found high rates of tobacco exposure with more than 75% having salivary cotinine above the level of detection. One-half reported being treated, at the time of hospitalization, with an asthma controller medication. Roughly 25% reported having been hospitalized in the preceding year for asthma, and nearly 18% were rehospitalized within 12 months of their index admission. Nearly 24% spent part of their index admission in the intensive care unit. A history of atopy was similarly common, with nearly 64% reporting a previous diagnosis of allergic rhinitis and 57% reporting eczema. A total of 55% had their index hospitalization in a fall season. Compared with enrolled children, those who were eligible but not enrolled did not differ with respect to age or sex. Enrolled children were, however, more likely to be African American and publicly insured. These differences were the same in the full GCARS cohort of children aged 1–16 years.

Greater than 50% of children were sensitized to each of *Alternaria*, *Aspergillus*, *D. pteronyssinus*, *D. farinae*, cat dander, and dog dander (Table 2). Nearly 30% were sensitized to cockroaches while 18% were sensitized to mouse. Greater than 91% of children were sensitized to one or more of the tested allergens; 68% to three or more.

Table 2 also shows the frequency with which in-home exposures were reported. A total of 17% of respondents reported mold or mildew in their home; 12% reported the presence of cockroaches. Greater than 40% reported one or more adverse in-home exposures; 12% noted three or more. Greater than 70% reported the presence of in-home wall-to-wall carpet, and 51% furry pets.

Table 3 indicates that African American children were at significantly higher risk of sensitization to *Alternaria*, *Aspergillus*, cockroach, and dust mite (all $P < 0.01$). For example, 35% of African American children were sensitized to cockroach compared with 16% of white children. White children, on the other hand, were significantly more likely to be sensitized to mouse, cat, and dog (all $P < 0.01$). Race was not associated with likelihood of being sensitized to three or more allergens. Similar patterns were noted for insurance coverage, with those publicly insured more likely sensitized to *Aspergillus* and cockroach (both $P < 0.05$) and those privately insured more likely sensitized to cat and dog (both $P < 0.05$). Income was significantly associated with cockroach, cat, and dog sensitization. Children in households reporting income less than $15,000/year were much more likely to be sensitized to cockroach compared with those in households reporting income at or exceeding $90,000/year (35 vs. 9%; $P < 0.01$). The income gradient reversed for sensitization to cat and dog, with higher income children at significantly increased risk of sensitization (both $P < 0.01$).

Reported history of hospitalization was significantly associated with sensitization to *Alternaria*, *Aspergillus*, cockroach, and dust mites (each $P < 0.05$). Associations with rehospitalization trended toward but did not reach statistical significance. Similar patterns were noted for severity of hospitalization; however, just an association with sensitization to dust mite reached significance ($P < 0.05$). Those reporting a previous diagnosis of allergic rhinitis were more likely to be sensitized to each tested allergen (all $P < 0.05$); 77% of those with a history of allergic rhinitis were sensitized to three or more allergens compared with 52% without such a history ($P < 0.01$). Season seemed to show relevance only for *Alternaria* and *Aspergillus*, with those being hospitalized in the fall having the highest sensitization rates (both $P < 0.01$).

Figure 1 illustrates patterns of co-occurrence between allergen sensitizations and reported exposures. Variables (e.g., specific sensitizations) that are closer in space are more likely to have co-occurred. For example, sensitizations to *Alternaria* and *Aspergillus* are close together, as are sensitizations to *D. pteronyssinus* and *D. farinae*. This indicates that patients sensitized to one mold (or one dust mite) were more likely to also be sensitized to the other tested mold (or the

Table 1. Sample characteristics of those enrolled in Greater Cincinnati Asthma Risks Study*

	n (or Median)	Percentage (or IQR)
Age, yr	8.0	4.9
Race		
African American	292	61.2
White	149	31.2
Other	36	7.6
Male sex	321	67.2
Insurance		
Public	334	70.0
Private	120	25.2
Other	23	4.8
Income		
<$15,000	158	33.4
$15,000–$29,999	123	26.0
$30,000–$59,999	105	22.2
$60,000–$89,999	49	10.4
⩾$90,000	38	8.0
Salivary cotinine		
Above level of detection	340	76.6
Below level of detection	104	23.4
Exposure to carbon attributable to traffic		
Above sample median	237	50.6
Below sample median	231	49.4
Report being treated with asthma controller medication(s)	237	49.6
Report history of asthma-related hospitalization in last year		
0	355	74.6
1	74	15.6
⩾2	47	9.9
Report history of asthma-related emergency or urgent care visit in last year		
0	234	49.2
1	87	18.3
⩾2	155	32.6
Report history of asthma-related systemic steroid use in last year		
0	201	42.4
1	103	21.7
⩾2	170	35.9
Rehospitalized in 12 mo after index hospitalization	85	17.8
Index hospitalization included stay in intensive care unit	112	23.6
Atopic history		
History of allergic rhinitis	304	63.6
History of eczema	273	57.1
Season of index hospitalization		
Summer (2010, 2011)	54	11.3
Fall (2010, 2011)	265	55.4
Winter (2010–2011)	56	11.7
Spring (2011)	103	21.6

Definition of abbreviation: IQR = interquartile range.
*Enrolled children aged 4–16 years (n = 478).

other dust mite). The thickness of lines connecting different variables illustrates the frequency of co-occurrence—thicker lines illustrate relationships in higher quartiles (i.e., more frequent co-occurrence). For example, the close and thick linkages between the two molds and the two dust mites suggest that cosensitization to both occurred more frequently. Thus, the tested molds, and the two tested dust mites, had both an increased likelihood of and more frequent cosensitization. The network analysis also demonstrates that reported adverse environmental exposures (e.g., mold, cockroach) are only weakly linked to allergen sensitizations. Although reported exposure to carpet is depicted in relatively close proximity to molds and dust mites, and reported furry pets in relatively close proximity to cat and dog, other exposures all appear further away and with thinner connections to allergen sensitizations.

Discussion

Indoor allergens are highly relevant to the expression of asthma morbidity. This study is the first, to our knowledge, to investigate allergen sensitization profiles and reported in-home environmental exposures in a population-based sample of children hospitalized for asthma. We found that nearly 70% of children hospitalized with asthma were sensitized to three or more common indoor allergens and that greater than 40% reported at least one adverse in-home exposure. Allergen sensitization varied significantly, and in different ways, across sociodemographic and clinical factors. However, when allergens were examined in aggregate (i.e., children with ⩾3 sensitizations), such gradients were lost. A network analysis provided the reason—certain sensitizations often co-occurred, and clustering was not random. Such patterns, however, were only weakly related to reported in-home exposures. These findings suggest that in-hospital allergen testing and medical management may be warranted and that the clustering of allergens might offer insights into future tailored interventions.

We found allergen sensitization to be common among children hospitalized with asthma—91% were sensitized to one or more allergens, 68% to three or more. In a study using National Health and Nutrition Examination Survey (NHANES) data, Stevenson and colleagues demonstrated sensitization rates, measured via skin prick, lower than what we found in our inpatient asthmatic sample (17). NHANES was designed as a nationally representative sample; however, it differs from an inpatient population. The Inner City Asthma Study (ICAS) was a sample likely more similar to our own, an outpatient cohort of urban children, aged 5–11 years, with moderate to severe asthma. To be eligible for the ICAS,

Table 2. Allergen sensitization and reported in-home exposure frequencies for enrolled children*

	n	Percentage
Allergen sensitization (IgE ⩾ 0.35 kU/L)		
Alternaria alternata/A. tenuis	253	58.8
Aspergillus fumigatus	234	55.3
American cockroach	119	28.0
Mouse epithelium	78	18.2
Dermatophagoides pteronyssinus	246	57.5
Dermatophagoides farinae	258	60.0
Cat dander	233	54.4
Dog dander	279	64.7
Number of allergen sensitizations†		
0	38	8.8
1	30	6.9
2	71	16.4
⩾3	294	67.9
Reported in-home exposures		
Mold or mildew	81	17.2
Water leaks	120	25.4
Cockroaches	58	12.2
Rodents	42	8.9
Cracks or holes in the walls or ceiling	115	24.5
Number of reported in-home exposures		
0	274	57.7
1	75	15.8
2	67	14.1
⩾3	59	12.4
Reported in-home carpet	340	71.7
Reported in-home furry pets	242	51.1

*Enrolled children aged 4–16 years (n = 478).
†For computation of cumulative number of allergen sensitizations, dust mite was considered a single entity (could be sensitized to either *Dermatophagoides pteronyssinus* or *D. farinae* and still be counted as one).

children needed to have had an emergency department visit or hospitalization in the preceding 6 months. These children were found to be highly sensitized to allergens such as mold, cockroach, rodent, dust mites, cat, and dog—94% had a positive skin test result to at least one of these allergens (15). Although we used serum-specific IgE instead of skin testing (22), we tested for similar allergens. Like the ICAS, our sample represented a high-risk group of patients. Unlike the ICAS, our sample included hospitalized patients, in the midst of exacerbation. The inpatient setting may be a good opportunity to pursue serum-specific IgE testing given that outpatient follow-up does not always occur.

There are verified links between allergen sensitization and exposure and both diagnosis of asthma (35) and asthma morbidity (12, 15). Although we saw trends toward associations between allergen sensitization and risk of rehospitalization, and severity of hospital course, relationships mostly did not meet statistical significance. This likely indicates that these analyses were underpowered. We did, however, find significant relationships between sensitization to molds, cockroach, and dust mites and reported history of hospitalization in the previous year. Thus, sensitization in our inpatient population may have contributed to their hospitalization. Wang and colleagues identified that children with asthma who are sensitized to environmental allergens are more likely to have increased health care and medication use, and that serum IgE and skin prick testing can serve as "markers of severe asthma for inner-city children" (12). Similarly, Matsui and colleagues showed that higher serum IgE levels corresponding to cockroach, mouse, dust mite, and cat were associated with poorer lung functioning and higher rates of exacerbations among outpatient children (36). Such findings complement our own, highlighting the potential relevance of allergen sensitization to the acute, inpatient setting.

We found significant relationships between certain allergens and sociodemographic factors; however, relationships often went in differing directions. For example, sensitization to allergens commonly associated with substandard housing (e.g., cockroaches) was more likely present for lower income patients. Alternatively, higher income individuals were more likely sensitized to cats and dogs. Similar gradients have been noted for reported environmental exposures in a cohort of asthmatic outpatients sampled from a managed care organization (37). Interestingly, we also found that mouse sensitization was more common among white children and trended toward being more common among middle and higher income individuals. This stands in potential contrast to evidence demonstrating a strong relationship between mouse sensitization and asthma morbidity among lower income, inner-city patients (38). In Baltimore, mouse sensitization and exposure have been shown to be common and consistently linked to adverse outcomes (16). It is unclear, from our data, if mouse allergy reaches the same level of significance in greater Cincinnati.

The high rate of atopy on the inpatient asthma unit warrants a reevaluation of how chronic management could be initiated or modified before discharge. Identification of allergies may impact clinical decision making. For example, allergy testing (22) may allow for more sophisticated asthma phenotyping. Studies have identified asthma phenotypes, or clusters, that are potentially amenable to more tailored medical care (39, 40). Indeed, medication changes or optimization, such as targeted addition of antihistamines, allergen-specific immunotherapy (23, 24), or omalizumab; or referrals for in-home exposure assessment and remediation have the potential to reduce future exacerbations and improve asthma control (25–27). Initiation of in-home assessments may be particularly relevant given that reported exposures often differ from what is truly found in the home (21). The inpatient population could be an apt starting point for initiation of such assessments and interventions. Such actions—both allergy testing and home remediation—warrant further cost-effectiveness analyses to determine whether they should be adopted more broadly.

Table 3. Bivariate associations between allergen sensitization and selected patient characteristics

	Percentage Sensitized to Allergen as Determined by Serum IgE ⩾ 0.35 kU/L							
	Alternaria	*Aspergillus*	American Cockroach	Mouse	Dust Mite (*D. pter.* or *D. farinae*)	Cat	Dog	Three or More Allergens
All	58.8	55.3	28.0	18.2	62.4	54.4	64.7	67.9
Race								
African American	**66.8***	**67.8***	**34.5***	**13.4***	**68.8***	**44.3***	**59.3***	69.8
White	**45.2***	**31.1***	**16.0***	**26.9***	**51.1***	**73.1***	**75.6***	65.2
Other	**51.5***	**54.5***	**24.2***	**21.2***	**57.6***	**59.4***	**63.6***	63.6
Insurance								
Public	60.4	**59.3†**	**33.7***	16.9	65.8	**49.2***	**60.9†**	68.6
Private	55.7	**44.7†**	**12.4***	19.8	53.8	**68.9***	**74.5†**	66.0
Other	52.4	**50.0†**	**25.0***	28.6	57.1	**57.1***	**71.4†**	66.7
Income								
<$15,000	60.8	58.8	**35.4***	14.1	67.6	**42.9***	**54.1***	67.3
$15,000–$29,999	58.7	57.8	**30.8***	16.8	60.9	**49.1***	**64.6***	66.4
$30,000–$59,999	54.3	50.0	**21.5***	24.5	60.6	**67.0***	**71.3***	70.2
$60,000–$89,999	61.9	50.0	**22.0***	19.1	59.5	**71.4***	**78.6***	71.4
⩾$90,000	60.6	53.1	**9.1***	21.2	54.6	**69.7***	**78.8***	66.7
Salivary cotinine								
Above LOD	56.0	54.9	29.7	20.1	62.9	**51.0***	62.6	67.0
Below LOD	64.2	52.7	20.2	14.9	60.0	**68.1***	71.6	70.5
Exposure to carbon attributable to traffic								
Above median	60.6	56.6	30.9	20.2	63.0	52.7	66.4	70.5
Below median	56.6	54.3	26.0	16.6	62.4	56.4	63.4	65.7
Report being on asthma controller medication(s)								
Yes	**64.8†**	**60.1†**	**32.7†**	19.9	66.2	54.3	64.8	72.0
No	**52.8†**	**50.5†**	**23.5†**	16.6	59.0	54.9	65.0	64.2
Report history of asthma-related hospitalization in last year								
0	**54.4***	**51.1***	**32.4†**	19.1	**58.3***	54.5	63.9	65.2
1	**69.6***	**64.7***	**30.4†**	17.4	**65.2***	52.5	63.8	73.9
⩾2	**77.5***	**73.2***	**55.0†**	12.8	**82.5***	53.8	70.0	80.5
Report history of asthma-related emergency or urgent care visit in last year								
0	57.7	51.0	31.1	16.9	60.1	53.1	62.9	68.1
1	60.8	57.0	34.2	16.5	61.3	58.8	60.0	61.7
⩾2	59.9	61.7	39.0	21.3	64.2	52.9	69.3	71.7
Report history of asthma-related systemic steroid use in last year								
0	**55.9†**	50.8	29.2	14.0	58.6	49.5	**59.7†**	64.5
1	**52.1†**	52.2	34.0	20.2	60.6	53.2	**61.7†**	64.9
⩾2	**67.4†**	63.6	39.7	22.6	65.5	60.5	**72.3†**	74.0
Rehospitalized in 12 mo after index hospitalization								
Yes	64.5	61.8	42.1	21.3	64.9	50.7	62.3	70.5
No	57.6	53.9	32.4	17.5	61.0	55.0	65.0	67.6
Index hospitalization included stay in intensive care unit								
Yes	65.0	63.6	38.0	19.2	**72.0†**	50.5	65.0	70.3
No	56.9	52.7	33.2	18.0	**58.5†**	55.2	64.3	67.5
History of allergic rhinitis								
Yes	**64.6***	**61.7***	**32.5***	**20.9†**	**68.3***	**62.6***	**73.5***	**77.0***
No	**49.7***	**46.9***	**17.7***	**11.9†**	**52.8***	**39.4***	**49.3***	**52.4***
History of eczema								
Yes	61.6	**62.7***	**32.8†**	19.1	**66.3†**	54.6	66.7	71.3
No	54.6	**46.2***	**21.8†**	16.9	**56.8†**	54.1	62.8	63.0

(Continued)

Table 3. (*Continued*)

	Percentage Sensitized to Allergen as Determined by Serum IgE ⩾ 0.35 kU/L							
	Alternaria	***Aspergillus***	**American Cockroach**	**Mouse**	**Dust Mite (*D. pter.* or *D. farinae*)**	**Cat**	**Dog**	**Three or More Allergens**
Season of index hospitalization								
Summer (2010, 2011)	**53.2***	**35.7***	32.6	23.4	53.2	53.2	68.1	60.4
Fall (2010, 2011)	**67.4***	**64.6***	26.7	15.3	65.4	53.5	63.4	70.5
Winter (2010–2011)	**46.9***	**40.8***	31.3	29.2	67.4	61.2	77.6	73.5
Spring (2011)	**45.7***	**47.8***	27.5	17.4	56.5	53.9	59.8	62.0

Definition of abbreviations: *D. farinae* = *Dermatophagoides farinae*; *D. pter.* = *Dermatophagoides pteronyssinus*; LOD = limit of detection.
Note: Significance indicated by boldface.
*Two-sided chi square or Mantel–Haenszel chi square ($P < 0.01$).
†Two-sided chi square or Mantel–Haenszel chi square ($P < 0.05$).

The network analysis provides a novel tool with which to conceptualize and visualize relationships between allergens and may impact how clinical decisions are made. Not surprisingly, the network analysis highlighted close linkages between the two molds and between the two dust mites. We also found that sensitization to molds was more likely to co-occur, and frequently co-occurred, with sensitization to dust mites. This is consistent with demonstrated associations between the verified presence of in-home mold and dust (41). Reported exposures were only weakly related to sensitizations—again, consistent with previous work highlighting the disparity between reported and true exposure (21). For example, although the network analysis

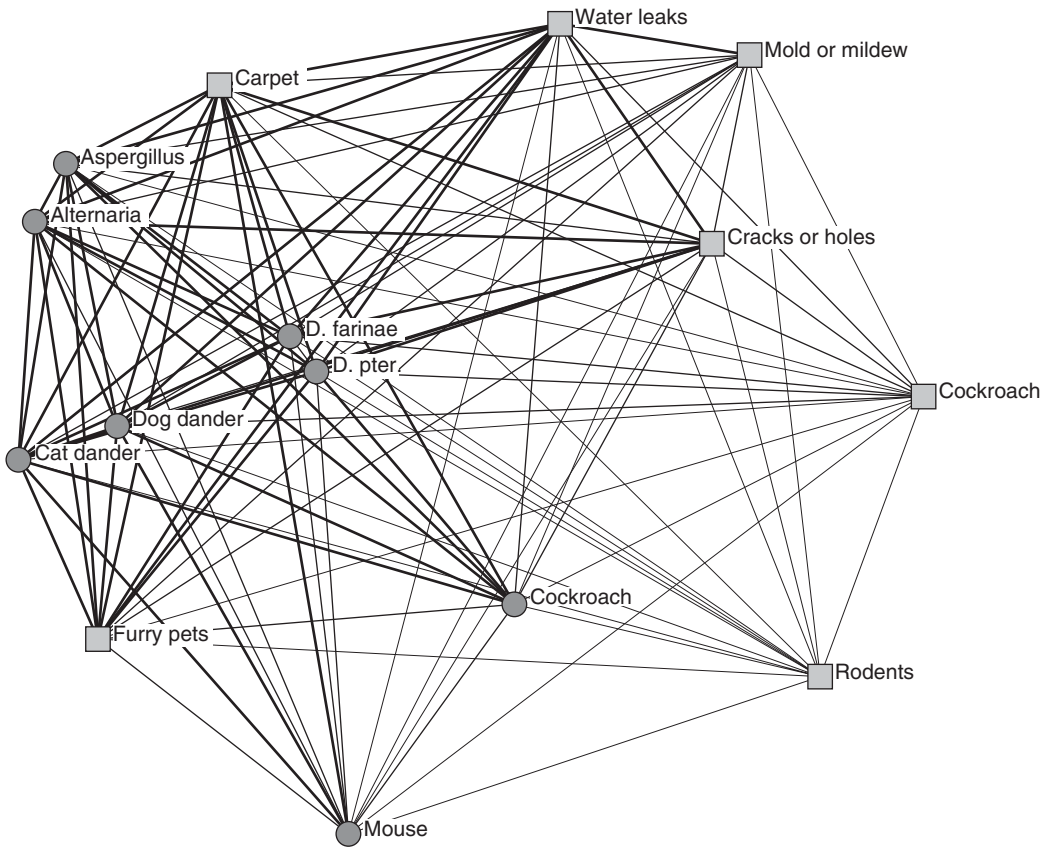

Figure 1. Relationships between allergen sensitizations and reported in-home exposures depicted using network analysis. *Circles* represent allergen sensitizations; *squares* represent reported in-home exposures. Multidimensional scaling was achieved in 89 iterations and the resulting stress of 0.067 indicated a good fit. Proximity between variables illustrates likelihood of co-occurrence. Thickness of ties between variables illustrates frequency of co-occurrence. D. farinae = *Dermatophagoides farinae*; D. pter. = *Dermatophagoides pteronyssinus*.

depicts reported cockroach presence in relatively close proximity to cockroach sensitization, the relationship remains weak. Reporting adverse in-home exposures such as cockroaches may be prone to social desirability bias, with respondents potentially reluctant to divulge substandard housing conditions. It is also possible that children may be exposed in more than one location (e.g., grandparent's home, school) (42). Still, the link between sensitization and exposure is well established, and we expect our data represent an underreporting or underrecognition of true exposure. This may represent an argument for more directed allergen testing or, potentially, in-home assessments for those individuals with asthma at highest risk.

In-home assessments, or interventions directed at improving housing stock, may be an effective way to screen for and mitigate allergen exposures. Many have shown the impact environmental exposures have on asthma morbidity and the ubiquity of potentially harmful allergens (7, 43). Still, some have shown that reported exposures are rarely acted on, that interventions aimed at more detailed assessment or remediation are uncommon even though such action may improve symptoms and reduce disparities (37, 44). For example, in Lowell, Massachusetts, an in-home environmental assessment and subsequent intervention to decrease triggers led to health improvements and cost savings for a population of low-income children with asthma (45). Locally, we have found success through relationships with health department housing inspectors (27) and a medical–legal partnership (46, 47). Such interventions could play a significant role in the promotion of chronic asthma control for high-risk children.

There were limitations to this study. First, the case definition for asthma used in this study was based on physician evaluation. This leaves open the possibility that some children, particularly younger children, could have virally induced wheezing and not chronic asthma. Second, allergens tested as part of this analysis are primarily found indoors, although the tested molds may also be found outdoors. Clearly, outdoor allergens are relevant, especially during spring and fall, which were the seasons with the highest admission rates. In the future, we plan to look more specifically at outdoor allergens, such as tree and grass pollens. Third, our sample was composed of children from greater Cincinnati, thereby limiting generalizability. Sensitization and exposure patterns may, indeed, differ across geographic regions. Fourth, exposures were measured by self-report; there was no in-home inspection. This may have contributed to unreliable exposure data. Still, although environmental histories are frequently uncommon on the inpatient asthma units, in-home environmental assessments as a part of clinical care are even less common (48).

Conclusions

Nearly 70% of patients in a population-based cohort of children hospitalized with asthma were sensitized to three or more indoor allergens. Future studies will assess the impact of both indoor and outdoor allergen sensitization on asthma morbidity after discharge from the hospital, and how allergens contribute to asthma-related disparities. We also plan to explore how knowledge of inpatient allergen sensitization profiles could be translated into testable clinical and environmental interventions aimed at reducing both morbidity and disparities. ■

Author disclosures are available with the text of this article at www.atsjournals.org.

Acknowledgment: The authors thank clinical research coordinators Hadley Sauers, Emily Greenberg, Angela Howald, Elizabeth Monti, Stacey Rieck, and Heather Strong for their support and dedication.

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