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Impact of the Home Indoor Environment on Adult Asthma and Rhinitis

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great deal of research has focused on the etiologic role of the home indoor environment in new-onset asthma and rhinitis. The effect of the same factors on established asthma has not been well studied, particularly among adults. Even less is known about the home environment's relationship to health status in rhinitis, despite its frequent comorbidity in asthma.

Allergen exposure is presumed to be an aggravating factor for asthma and rhinitis in the home indoor environment; reduction in the home allergen burden, especially through dust mite control, is recommended for better disease management, although the controlled data supporting even this intervention have been debated.¹⁻⁶ Beyond a discrete set of common allergens, other components of the indoor home environment typically are assessed on an exposure-by-exposure basis, rather than in combination. Such exposures include secondhand smoke^{7,8}; nitrogen dioxide⁹⁻¹¹; mold, mildew, and moisture¹²; volatile chemicals¹³; and endotoxin and glucans.¹⁴⁻¹⁶ Encompassing a broad range of potential home environmental risk factors within any single study presents a major research challenge.^{3,17-19}

We investigated the combined effects of multiple aspects of the home indoor environment on adult asthma and rhinitis, including allergens, endotoxin, and indoor air quality (IAQ) measurements. We assessed multiple outcomes, including lung function, chronic disease-specific severity, general health status, and asthma-specific quality of life. This approach

Learning Objectives

- Recall associations among different home environments (especially with and without a pet), indoor air quality, and specific allergic sensitization.
- Summarize ways in which the presence of allergens and indoor air quality relate to lung function and general health status.
- Identify relationships between the home environment and health outcomes that remained significant after multivariate analysis.

Abstract

Objective: We sought to study the combined effects of multiple home indoor environmental exposures in adult asthma and rhinitis. **Methods:** We studied 226 adults with asthma and rhinitis by structured interviews and home assessments. Environmental factors included dust allergen, endotoxin and glucan concentrations, and indoor air quality (IAQ) variables. Outcomes included forced expiratory volume in 1 second (FEV₁) percent predicted, Severity of Asthma Score (SAS), Short-Form (SF)-12 Physical Component Scale (PCS), and asthma Quality of Life (QOL) score. **Results:** House dust-associated exposures together with limited IAQ variables were related to FEV₁ % predicted ($R^2 = 0.24$; $P = 0.0001$) and SAS ($R^2 = 0.18$; $P = 0.007$). IAQ and limited dust variables were associated with SF-12 PCS ($R^2 = 0.15$; $P = 0.02$), but not QOL ($R^2 = 0.13$; $P = 0.16$). **Conclusions:** The home environment is strongly linked to lung function, health status, and disease severity in adult asthma and rhinitis. (J Occup Environ Med. 2005;47:362-372)

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is predicated on a model in which multiple factors act in concert, not simply individually, to affect asthma and rhinitis.

Materials and Methods

Initial Subject Recruitment

All aspects of the study were conducted following institutional Committee on Human Research review. Subjects with asthma were recruited through a random sample of pulmonary and allergy specialists in northern California beginning in 1992, followed by a sample of family medicine practices in 1996.^{20,21} In 1999, a third group of subjects was recruited by random-digit dialing in the community at large within the same Northern California area.²² The latter sample included subjects reporting a physician's diagnosis of asthma, a diagnosis of rhinitis, or a diagnosis of both conditions. Findings from baseline and follow-up interviews have been reported previously.^{23–30}

Follow-Up for Telephone Interviews and Home Visits

In total, 548 eligible subjects completed the interview wave conducted prior to the one used in this study (2002–2003). Of the potential subjects for follow-up, 6 (1%) had died, 114 (21%) declined participation, 12 (2%) could not be recontacted successfully, and 416 were interviewed (76%). Among the original physician-recruited group, 281 (81%) were reinterviewed (228 from the pulmonary-allergy; 53 from the family practitioner recruitment). Among the population-based group, 135 (68%) were interviewed. This included 76 individuals with rhinitis but no concomitant asthma.

Excluding those who had moved out of the study geographic range of northern California from Fresno to the Oregon border, 390 interviewed subjects were eligible for home visits. Forty-nine declined a home visit at the completion of the structured phone interview; 115 additional sub-

jects declined upon inquiry to schedule a visit. A total of 226 (58%) home visits were ultimately completed. Of these, 121 (54%) were from the SF–Oakland–San Jose Consolidated Metropolitan Statistical Area (CMSA), 44 (19%) from the Sacramento CMSA, and 61 (27%) from elsewhere in Northern California. The median time elapsed between interview and home visit was 8.1 weeks (57 days). There were only minor differences (Table 1) between subjects who did and did not undergo home visits.

Subject Telephone Interviews

Subjects were interviewed with a structured telephone survey that averaged 45-minutes in length, using computer-assisted telephone interview software. The median time elapsed since the last interview and follow-up was 22 months. Core components of the questionnaire were based on items developed for and used in multiple previous waves of the study and thus have been tested thoroughly. These include an extensive survey of prescription and over-the-counter medication use, medical care utilization and costs during the 12 months before interview, annual household income, employment data, and cigarette smoke exposure. Factors in the home environment that could adversely affect the subject's asthma or allergic rhinitis condition were also elicited in the telephone survey, as well as in a later home visit.

Health Status, Disease Severity, and Disease-Specific Quality of Life

General health status was assessed with the SF-12, yielding the Physical Component Scale (SF-12 PCS) scores. The SF-12 PCS has a normative score of 53 ± 7 among US adults aged 18–44 years without chronic morbidity.^{31,32} Asthma severity was quantified with the Severity of Asthma Score (SAS), a previously validated measure that

includes current symptoms, recent medication use, and lifetime experience of certain types of health care utilization.^{33,34} A maximum score of 28 reflects the greatest asthma severity. Subjects in the cohort who did not report a physician's diagnosis of asthma were nonetheless asked the component questions and could achieve scores greater than zero. The Marks Asthma Quality of Life (QOL) questionnaire, a validated, asthma-specific instrument using a 20-item Likert-type scale adapted for telephone administration, was administered only to subjects with asthma.^{35,36} A maximum summary score of 60 reflects the greatest adverse effects of asthma on QOL.

Lung Function

Home visit spirometry was performed using an EasyOne Spirometer (ndd Medical Technologies, Chelmsford, MA). The EasyOne meets ATS 1994 diagnostic standards for spirometry measurements.³⁷ Spirometry measurements, including forced expiratory volume in 1 second (FEV₁), were taken using a standard protocol conforming to ATS guidelines.³⁸

Serum-Specific and Total IgE and Serum Cotinine

Overall, 214 blood samples were analyzed for IgE (11 declined analysis; 1 specimen lost). There were 199 samples with serum cotinine results for analysis after further excluding 14 subjects who reported current smoking and 2 others who denied smoking but had cotinine levels that indicated active smoking. Active smokers were only excluded from the cotinine analyses in this study.

Samples were assayed for specific IgE antibodies for cat, dog, cockroach, and dust mites (both Der p 1 and Der f 1) (Unilab Corporation, San Jose, CA), using standard allergens covalently coupled to ImmunoCAP for assays corresponding to the allergens we also measured in dust (see below). Total serum IgE antibody concentrations were quantified

TABLE 1
Subject Characteristics by Home Visit Participation Status

Subject Characteristics	Home Visit Status			P Value
	Completed (n = 226)	Not Completed (n = 190)	All Subjects (n = 416)	
Age, mean (SD)	45 (9)	46 (9)	46 (9)	0.46
Female, n (%)	156 (69%)	138 (73%)	294 (71%)	0.49
Education,* n (%)				0.47
Did not graduate high school	2 (1%)	3 (1%)	5 (1%)	
High school graduate	32 (14%)	27 (14%)	59 (14%)	
Some college	71 (31%)	66 (35%)	137 (33%)	
College graduate	77 (35%)	60 (32%)	137 (33%)	
Masters or PhD	43 (19%)	34 (18%)	77 (19%)	
Annual family income,* n %				0.34
Less than \$20,000	21 (9%)	9 (5%)	30 (7%)	
\$20,000-\$40,000	37 (16%)	20 (11%)	57 (14%)	
\$40,000-\$60,000	32 (14%)	33 (17%)	65 (16%)	
\$60,000-\$80,000	35 (16%)	41 (21%)	76 (18%)	
\$80,000-\$100,000	36 (16%)	31 (16%)	67 (16%)	
More than \$100,000	60 (27%)	43 (23%)	103 (25%)	
Missing	5 (2%)	13 (7%)	18 (4%)	
Employment status, n (%)				0.55
Working	164 (73%)	143 (75%)	307 (74%)	
On leave	3 (1%)	4 (2%)	7 (2%)	
Unemployed	10 (4%)	8 (4%)	18 (4%)	
Unable to work	23 (10%)	11 (6%)	34 (8%)	
Other	26 (12%)	24 (13%)	50 (12%)	
Race, n (%)				0.40
White or other	184 (81%)	162 (85%)	346 (83%)	
Black	13 (6%)	7 (4%)	20 (5%)	
Asian	10 (4%)	12 (6%)	22 (5%)	
Pacific Islander	8 (4%)	3 (2%)	11 (3%)	
Native American	11 (5%)	6 (3%)	17 (4%)	
Latin or Hispanic origin, n (%)	27 (12%)	21 (11%)	48 (12%)	0.90

Home visit status "not completed" includes both ineligible subjects outside geographic range and subjects who declined the home visits after completing telephone interviews.

*Mantel-Haenszel χ^2 for trend reported for education and income after excluding missing subjects (educational status missing for one subject; income for 18 subjects).

according to standard methods at the same commercial laboratory. Total IgE concentrations were divided into three categories of likelihood for atopy: low (<25 kU/L), equivocal (25 to 100 kU/L), and probable (>100 kU/L) IgE. The limit of detection was 2 kU/L for total IgE and 0.35 kU/L for the specific IgE tests.

Concentrations of cotinine in blood were determined using liquid chromatography–tandem mass spectrometry (LC-MS/MS). Deuterium-labeled cotinine (cotinine- d_9) was used as an internal standard.³⁹ The limits of quantification and detection for cotinine were 0.2 ng/mL and 0.05 ng/mL, respectively.

Home Environment Checklist and IAQ

A home environment checklist included the presence of pets and signs of moisture (based on damp patches obvious by direct visual inspection of the living room and bedroom ceilings and walls) or mildew (based on mold or mildew obvious by direct visual inspection of the bathroom ceiling, walls, tiled surfaces, and curtains). IAQ measurements were taken for at least 5 minutes in a maximum of three locations: the subject's bedroom, the room in which the greatest amount of nonsleeping time was spent (typically, a family

room or living room), and the kitchen. Of 226 homes studied, 31 (14%) had a living arrangement that combined more than one of the predefined areas in a single living space. For analysis, a single set of IAQ values was generated based on the averaged value for the subject's sleeping area, habitation area, and kitchen. Of the 226 subjects, there were 208 (92%) for whom all IAQ endpoints were available for analysis.

Carbon monoxide, carbon dioxide, humidity, and temperature were measured with the IAQ Monitor (model aq-5000, Quest Technologies, Oconomowoc, WI). Relative humidity was measured with a ca-

passive detector, carbon monoxide was measured with an electrochemical sensor, and carbon dioxide was measured with a nondispersive infrared detector. Moisture was measured at multiple sites with the NO-PINS Moisture Meter, Model CT100 (Electrophysics, London, Ontario, Canada) and averaged to generate a single value.

Nitrogen Dioxide, Formaldehyde, Acrolein, and Volatile Organic Compounds

Palmes tube passive samplers were used to test for kitchen nitrogen dioxide.⁴⁰ Aldehyde, acrolein and volatile organic compounds (VOCs) were assessed using passive diffusion monitoring badges (Assay Technology Analytical Laboratory, Pleasanton, CA). Subjects returned monitors after 1 week's sampling time. Most samples (74%) were kept in the home for 7 days; 91% between 5 and 9 days. Nine subjects did not return a Palmes tube, leaving 217 analyzed spectrophotometrically by the ESE Lab (Harvard School of Public Health, Boston, MA). The limit of detection (LOD) for 1 week of sampling was 1.0 part per billion (ppb) nitrogen dioxide.

In total, 226 badges of one of the three organics were available from 213 households for analysis: 71 acrolein, 130 aldehyde, and 26 VOCs. The badges were analyzed by their manufacturer. The LOD for formaldehyde is 0.05 µg and for acrolein is 0.5 µg per badge. For VOCs, the LOD is dependent on the substance analyzed: benzene = 0.5 µg; ethyl benzene = 0.5 µg; toluene = 0.5 µg; xylene = 0.6 µg.

Dust Sampling

The dust sampling was designed to collect two samples of at least 200 mg of dust, one from the subject's bed and one from the floors of the kitchen and living room, using a Shark vacuum cleaner (Euro-Pro Turbo Hand Vacuum, Model EP033).⁴¹ The mattress pad and pil-

lows of the bed were vacuumed for 8 minutes at 250 to 550 L/min; the kitchen floor was vacuumed for 2 minutes and the living room floor for 6 minutes. Vacuuming was performed through a stainless-steel wire mesh screen that removed very large particles (opening size 0.014" square) and a final filter (37 mm cellulose support pad) that retained small particles. Each minute, prefilter dust was removed.

Of 226 households, 223 samples were collected from the bed and 223 collected from the kitchen/living room floors. No data at all were obtained from one household; for two beds and two kitchen/living room floors no sample was collected. Three bed samples and one kitchen/living room floor sample had insufficient amounts of dust for analysis, leaving a total of 220 bed and 222 kitchen/living room floor samples that could be analyzed.

Dust Analysis of Allergens

All dust samples were analyzed for allergens by the laboratory of Dr S. Katharine Hammond (University of California Berkeley). Samples weighing less than 200 mg were evenly divided so that a minimum amount (>25 mg) per four aliquots per sample could be maintained. Samples were kept frozen until extraction. For allergen analysis, extraction used 5 mL of 0.05% Tween 20 (PBS-T, pH 7.4) per aliquot; the tubes were gently rotated for 2 hours, then centrifuged for 20 minutes at 2500 rpm. Supernatants were analyzed for each of five allergens: dog (Can f 1), cat (Fel d 1), cockroach (Bla g 1), and two types of dust mite (Der p 1 [*Dermatophagoides pteronyssinus*] and Der f 1 [*Dermatophagoides farinae*]) using enzyme-linked immunosorbent assays (ELISAs). These are the allergens that are routinely measured in most studies assessing indoor exposure to cat, dog, cockroach, and dust mite (although Der f 1 and Der p 1 not always both sampled in the same study).^{1,2,5,18}

All ELISA kits, including antibodies and standards, were purchased from Indoor Biotechnologies (Charlottesville, VA). The allergen concentrations were calculated by using the standard curve and quantified in micrograms (µg) of allergen per gram of dust (cat, dog, and mites) or units (U) per gram of dust (cockroach). The LODs (quantification limits) in micrograms allergen per gram of dust were dog, 0.1 (0.20); cat, 0.06 (0.50); dust mite [Der f 1 or Der p 1], 0.10 (0.78); for cockroach, the LOD was 0.78 U/g (3.13 U/g).

Endotoxin and Glucan Assays

Dust samples were analyzed for endotoxin and glucan at the University of Iowa Environmental Health Sciences Research Center. Samples were eluted as 50 mg/mL in pyrogen-free water containing 0.05% Tween 20 and shaken for 1 hour at room temperature. Samples were centrifuged for 20 minutes at 600 × g at 4°C; 0.1-mL aliquots of supernatant were removed to pyrogen-free cryovials for analyses.

Endotoxin was analyzed using the Limulus Amebocyte Lysate Kinetic-QCL Test Kit (BioWhittaker).⁴² Dilutions of standards were performed in cleaned borosilicate glass tubes (heated more than 2 hours in a 200°C oven to remove endotoxin). Twofold serial dilutions of endotoxin standards were prepared using pyrogen-free water containing 0.05% Tween 20. A 12-point calibration curve ranging from 0.05 to 100 EU endotoxin standard/mL gave a correlation = 0.997 to 0.998 based on maximum change of optical density over time.

Glucan was analyzed using a newly developed method. To extract glucan, 0.1 mL of 10 × PBS was added to diluents, which were shaken for 1 hour at room temperature, autoclaved for 1 hour at 120°C, shaken for 15 minutes, and centrifuged at 600 × g for 20 minutes at 4°C before supernatants were collected.

The amount of fungal glucan in the dust eluates was quantified by sandwich ELISA using custom

TABLE 2

Lung Function, Disease Severity, Health Status, and Asthma-Specific Quality of Life for Home Visit Participants

Health Measure	N	Mean (SD)	Correlation With SF-12 (P Value)	Correlation With Severity Score (P Value)	Correlation With Asthma QOL (P Value)
FEV ₁ Percent predicted	226	85.4 (18.4)	0.24 (0.002)	−0.43 (<0.0001)	−0.29 (−0.001)
SF-12 Physical component score	226	45.0 (11.1)	1.0	−0.39 (<0.0001)	−0.60 (<0.0001)
Severity of Asthma Score (SAS)	226	6.8 (5.3)	—	1.0	0.60 (<0.001)
Asthma quality of life (QOL) Score *	189	16.1 (15.2)	—	—	1.0

*Excludes 36 subjects with rhinitis alone but without a physician's diagnosis of asthma and 1 subject with missing data.

mouse anti-(1→3,1→6)- β -D-glucan monoclonal antibody as the capture antibody and rabbit anti-scleroglucan polyclonal antibody as the second antibody.

Statistical Analysis

We categorized the primary predictor variables related to the home environment into two general categories. The first category included allergens and IgE status, endotoxin, and glucan. Allergen levels were logarithmically transformed; where two detectable allergen values were available (eg, from the floors and bed), we used whichever was the higher. For endotoxin and glucan, values were averaged between the bed and floor values. We tested differences in allergen, endotoxin, and glucan levels by pet ownership status using the Wilcoxon rank sum test.

The second category of variables was related to IAQ, including serum cotinine (measuring secondhand smoke exposure) and indoor concentrations of various gases, humidity, and wall dampness. We recognized that some of the factors categorized as IAQ variables might act through either allergic or non-allergic pathways.

The primary outcomes studied were FEV₁ % predicted based on NHANES III derived equations, using separate predictive values for non-Hispanic whites, Hispanics, and blacks,⁴³ and the SF-12 PCS as a measure of general health status. Secondary outcomes were the SAS (a disease-specific severity measure paralleling FEV₁ % predicted) and

the asthma QOL score (a disease-specific measure paralleling the SF-12). We excluded from the QOL analysis subjects who reported rhinitis without concomitant asthma, because they were not asked to complete this disease-specific instrument as part of their interviews.

To assess the relationships between independent and dependent variables we used a stepped approach. First, we tested individual independent variables in linear regression models using FEV₁ % predicted and SF-12 PCS as the dependent variables. We also conducted sensitivity analyses limited to allergen exposure only in the subgroup sensitized to dust mite, cat, or dog. Additional analyses tested IAQ exposures on a room by room basis. Next, independent variables associated with $P < 0.20$ were entered into multivariate analyses. Because we tested clusters of related variables together, the first linear regression model was not univariate in all cases. If the P value associated with any one of the parameters in a cluster of variables was <0.20 , all of the variables in that cluster were included in the multivariate analysis. We reduced two variables that had been multilevel ordinal (number of plants and carpet pile depth) to dichotomous variables.

Results

Outcome Variable Frequency

Table 2 presents descriptive statistics and correlations among four key outcomes analyzed. For SF-12 PCS,

SAS, and asthma QOL, no statistically significant difference was detected in scores between those studied in the home visits and those who were not studied (data not shown). Among those with rhinitis alone ($n = 36$), 25 scored >0 on the SAS, consistent with possible concomitant asthma (the maximum score in this subgroup was 6 points).

Indoor Allergens and Endotoxin

The most common specific allergic sensitization (Table 3) was to dust mite: 77 (36%) were positive either for Der f 1 (70; 33%) or Der p 1 (76; 36%). Dust mite allergen was significantly higher in the homes of those who were sensitized ($P < 0.001$). Cat sensitization (67; 31%) and dog sensitization (31; 14%) frequencies also are shown in Table 3. Cat allergen levels were higher in the homes of current cat owners ($P < 0.001$), as were dog allergen levels among current dog owners ($P < 0.001$). No association was found between cat sensitization and current cat ownership ($P = 0.85$) or cat allergen concentration ($P = 0.99$). Similarly, there was no relationship between dog sensitization and current dog ownership ($P = 0.69$) or dog allergen concentration ($P = 0.46$).

Endotoxin and glucan were significantly correlated ($r = 0.35$; $P < 0.001$). Endotoxin levels were significantly higher in homes with dogs (median = 52 EU/mg dust) than those without (median = 36 EU/mg; $P = 0.008$). Similarly, glucan was also higher in dog owners' homes

TABLE 3

Dust Content and IgE Status Assessed in 226 Home Visits

Variable	<i>n</i>	Distribution
Total dust weights		
Kitchen/LR floor, median dust weight in mg, (25th to 75th IQR)	223	116 (55–255)
Bed, median dust weight in mg (25th to 75th IQR)	223	89 (36–189)
Dust mite allergy and exposure status		
Dust mite IgE positive for Der f 1 or p 1, <i>n</i> (%)	214	77 (36%)
Dust mite allergen $\mu\text{g/g}$ house dust, median (25th to 75th IQR)		
All subjects tested	225	0.1 (0–1.9)
IgE-positive subjects only	77	1 (0–5)
Pet ownership by IgE status		
Dog owner, <i>n</i> (%)	226	103 (46%)
Cat owner, <i>n</i> (%)	226	80 (35%)
Dog IgE positive, <i>n</i> (%)	214	31 (14%)
Cat IgE positive, <i>n</i> (%)	214	67 (31%)
Pet antigen in $\mu\text{g/g}$ house dust, median (25th to 75th IQR)		
Dog allergen, all subjects tested	225	12 (2–93)
Dog allergen, IgE-positive subjects only	31	26 (3–117)
Cat allergen, all subjects tested	225	5 (1–74)
Cat allergen, IgE-positive subjects only	67	4 (2–82)
Total serum IgE	214	
Low (<25 kU/L) for atopy, <i>n</i> (%)		55 (26%)
Equivocal (25 to 100 kU/L) for atopy, <i>n</i> (%)		78 (36%)
Probable (>100 kU/L) for atopy, <i>n</i> (%)		81 (38%)
Endotoxin in EU/mg dust, median (25th to 75th IQR)	214	42 (23–70)
Fungal Glucan in $\mu\text{g/g}$ house dust, median (25th to 75th IQR)	211	211 (124–426)

Dust antigen levels reported are the highest detected; endotoxin and glucan are averaged between the bed and floor samples.
IQR indicates interquartile range.

TABLE 4

Exposure Variables Related to IAQ Assessed in 226 Home Visits

Variable	<i>n</i>	Distribution
Serum cotinine (recent secondhand smoke exposure), <i>n</i> detectable (%)	199	35 (18%)
Wall dampness as percent moisture, mean (SD)	225	9 (2)
Air humidity as percent, mean (SD)	224	50 (9)
Air CO ₂ ppm, mean (SD)	221	760 (300)
Air CO ppm, mean (SD)	217	0.3 (0.8)
Houseplants, <i>n</i> (%) (none = referent)	226	
1–4		87 (39%)
5–10		65 (29%)
11 or more		33 (15%)
Damp living room or bedroom, <i>n</i> (%)	226	19 (8%)
Mold visible in bathroom, <i>n</i> (%)	226	40 (18%)
Air-filtering device, <i>n</i> (%)	226	57 (25%)
Heat source (other heating source = referent)	226	
Gas wall heating unit, <i>n</i> (%)		31 (14%)
Coal or wood heat, <i>n</i> (%)		35 (15%)
Kitchen NO ₂ ppb, mean (SD)	217	13 (14)
Kitchen formaldehyde ppb, mean (SD)	130	15 (10)
Kitchen gas stove or oven, <i>n</i> (%)	226	121 (54%)
Bedroom air conditioner, <i>n</i> (%)	226	62 (27%)
Bedroom humidity controls (no control = referent)	226	
Humidifier, <i>n</i> (%)		10 (4%)
Dehumidifier, <i>n</i> (%)		4 (2%)
Bedroom carpet status and pile depth (no wall-to-wall carpeting = referent)	226	
Wall-to-wall carpet pile <1", <i>n</i> (%)		57 (25%)
Wall-to-wall carpet pile $\geq$ 1", <i>n</i> (%)		100 (44%)

TABLE 5

FEV₁ % Predicted and SF-12 Physical Component Score in Relation to Antigens, Antibodies, Endotoxin, and Glucan
Dependent Variables Studied

Variables Tested in Unadjusted Models	n	FEV ₁ % Predicted		SF-12 PCS	
		β	SE	β	SE
Dust, kitchen/living room floor per 100 mg	223	-0.7†	0.5	0.2	0.3
Dust, bed per 100 mg	223	-2.0*	0.6	0.2	0.4
Dust mite allergen and specific IgE	214				
Dust mite specific IgE positive		-2.4	2.8	3.9*	1.6
Dust mite allergen (log)		0.3	0.3	0.1	0.2
Dog allergen and specific IgE	214				
Dog owner		-8.5*	3.3	-2.0	2.1
Dog IgE positive		-9.3*	3.5	-0.3	2.2
Dog allergen (log)		0.4	0.7	0.1	0.4
Cat allergen and specific IgE	214				
Cat owner		1.5	3.9	0.5	2.4
Cat IgE positive		-9.4*	2.7	0.1	1.6
Cat allergen (log)		-0.3	0.7	-0.3	0.4
IgE (Referent = IgE low for atopy)	214				
IgE equivocal (25–100 IU/L)		-7.7*	3.2	-0.1	2.0
IgE probable (>100 IU/L)		-8.9*	3.2	2.0	1.9
Endotoxin (referent = <25% quartile)	214				
25% to 50% quartile (>23, ≤42 EU/mg dust)		-6.2†	3.5	-1.1	2.2
50% to 75% quartile (>42, ≤70 EU/mg dust)		-2.9	3.6	-1.9	2.2
75% to 100% quartile (>70 EU/mg dust)		-2.7	3.5	-2.3	2.2
Glucan (Referent = <25% quartile)	211				
25% to 50% quartile (>124, ≤211 µg/g dust)		1.7	3.6	-3.8†	2.1
50% to 75% quartile (>211, ≤426 µg/g dust)		0.7	3.6	-2.4	2.1
75% to 100% quartile (>426 µg/g dust)		-0.1	3.6	-3.1†	2.2

* $P < 0.05$; † $0.05 < P < 0.20$.

Individual variables or variable clusters in bold were included in a multiple linear regression models of FEV₁ percent predicted or SF-12 PCS based on a cut off $P < 0.20$ (see Table 7).

(median = 0.29 µg/g dust) than those without (median = 0.17 µg/g) ($P = 0.001$). No statistically significant association was detected between cat ownership and levels of either endotoxin ($P = 0.48$) or glucan ($P = 0.19$). Cockroach-specific IgE was present in only 24 (11%) of 214 subjects; cockroach allergen was detected in only 6 of 225 (3%) of homes. We did not analyze this allergen further.

IAQ

The distributions for the IAQ variables are presented in Table 4. Of 199 nonsmoking subjects, 35 (18%) had detectable cotinine levels consistent with recent secondhand cigarette smoke exposure. Wall dampness and room air humidity were correlated ($r = 0.4$; $P < 0.001$), as were nitrogen dioxide and carbon dioxide ($r =$

0.23; $P = 0.001$). Nitrogen dioxide levels were higher in homes with gas stoves (median value = 11 ppb in 114 homes) than in those without (median = 6 ppb in 103 homes; $P < 0.0001$). Dust glucan concentrations did not correlate with measured wall dampness ($r = -0.02$; $P > 0.7$) and did not differ statistically by the presence of bedroom or living room wall dampness or bathroom mold. Formaldehyde was above the level of detection in all of the 130 homes sampled, although values were low (mean 15 ppb; maximum = 53 ppb).

We conducted acrolein and VOC testing in a subset of subjects. Further acrolein sampling was discontinued after initial testing yielded values below the level of detection for 41 (58%) of 71 samples tested. VOCs were nondetectable for benzene, toluene, xylene, or ethylben-

zene in 19 (70%) of 27 samples tested; in the 8 with detectable levels, toluene was the most frequent VOC quantified.

Allergens, Atopy, Endotoxin, and Glucan: Lung Function and Health Status

As shown in Table 5, every variable cluster tested demonstrated a relationship to FEV₁% predicted in the expected direction at the a priori cutoff of $P < 0.20$, except for dust mite sensitivity-allergen levels and dust glucan concentration by quartile. In contrast to this pattern, dust mite and glucan were the only independent variables associated with the SF-12 PCS. Of note, specific IgE to dust mite was associated with a higher SF-12 PCS (better health status). None of the other predictors

TABLE 6

FEV₁ % Predicted and SF-12 Physical Component Score in Relation to IAQ

Variables Tested in Unadjusted Models	n	Dependent Variables Studied			
		FEV ₁ % Predicted		SF12-PCS	
		β	SE	β	SE
Cotinine detectable	199	-2.2	3.5	0.2	2.1
Wall dampness (%)	225	0.3	0.5	-0.6*	0.3
Air humidity (%)	224	-0.1	0.1	0.02	0.08
Houseplants (referent = none)	226				
Any houseplants		0.7	3.5	6.0*	2.1
At least five, <10		-2.7	3.0	-2.3	1.8
11 or more		3.8	3.9	0.2	2.3
Damp patches in living room or bedroom	226	2.7	4.4	-4.1†	2.7
Mold visible in bathroom	226	-4.4†	3.2	-2.8†	1.9
Air filter	224	-4.2†	2.8	-2.6†	1.7
Heating (referent = other)	226				
Gas space heaters		6.3†	3.6	-1.7	2.2
Coal or wood heat		5.1†	3.4	3.4†	2.1
NO ₂ (ppb)	217	0.1	0.1	0.002	0.1
Gas stove or oven	226	1.6	2.5	0.7	1.5
Bedroom air conditioner	226	-1.2	2.7	-2.2†	1.7
Bedroom humidifier (referent = none)	226				
Humidifier		2.1	5.9	5.1†	3.6
Dehumidifier		17.0†	9.2	1.9	5.6
Carpet (Referent = none)	226				
Any wall-to-wall		0.8	3.3	3.5†	2.0
Wall-to-wall pile >1"		1.9	3.1	-0.1	1.8

* $P < 0.05$; † $0.05 < P < 0.20$ Individual variables or variable clusters in bold were included in a multiple linear regression models of FEV₁ percent predicted or SF-12 PCS based on a cut off $P < 0.20$ (see Table 7).

tested (Table 5) was associated with SF-12 PCS at the a priori screening cut-off of $P < 0.20$. In a sensitivity analysis limited to dust mite-sensitized subjects ($n = 77$), allergen concentration was not statistically associated with FEV₁ % predicted ($P = 0.22$) or SF-12 PCS ($P = 0.60$). Similar analyses limited to the cat sensitized ($n = 67$) and dog sensitized ($n = 31$) strata also failed to meet the a priori cut-off of $P < 0.20$.

IAQ: Lung Function and Health Status

Bathroom mold, air filtration, home heating type, and bedroom humidifier status were associated with FEV₁ % predicted; more IAQ variables were associated with SF-12 PCS at the a priori cut-off of $P < 0.20$ (Table 6). The only consistent relationships for both FEV₁ % predicted and for SF-12 PCS were for mold, presence of a household air

filter (poorer lung function and health status), and coal or wood heating (better function and status). Neither carbon dioxide nor carbon monoxide concentrations was associated with FEV₁ % predicted or SF-12 PCS at the $P < 0.20$ cutoff; a sensitivity analysis of IAQ variables by room (humidity, carbon dioxide, carbon monoxide) did not yield substantively different results (data not in Table). Formaldehyde was not significantly associated with FEV₁ % predicted ($3.4 \pm 3.1\%$ increase; $P = 0.28$) or SF-12 PCS score (3.1 ± 1.8 point increase; $P = 0.10$) [expressed per 20 ppb formaldehyde [2 SD] change] (data not shown in Table).

Multivariate Analyses

We tested a multivariate model for FEV₁ % predicted, including all of the individual variables meeting the $P < 0.20$ cutoff (Table 7). The model $R^2 = 0.24$ ($P = 0.0001$). Two variables

demonstrated statistically significant negative associations with FEV₁ % predicted: dog ownership ($-9.7 \pm 3.5\%$; $P = 0.006$) and total dust collected from the bed ($-1.8 \pm 0.6\%$ per 100 mg of dust; $P = 0.003$). We retested the same multivariate model using the SAS as the dependent variable (model $R^2 = 0.18$ $P = 0.007$). Dog ownership was also related to greater SAS (3.3 ± 1.1 ; $P = 0.002$); dog antigen with a statistically significant lower SAS (-0.5 ± 0.2 ; $P = 0.03$). The presence of an air filter was the only other variable also significantly associated with the SAS (in the direction of greater severity, 2.3 ± 0.9 ; $P = 0.01$).

The variables meeting the a priori cutoff of $P < 0.20$ in relation to SF-12 PCS were also tested together in a multivariate model (Table 7). This model had an $R^2 = 0.15$ ($P = 0.02$). Dust mite specific IgE was the only individual variable statistically

TABLE 7

Multivariate Models of FEV₁ % Predicted and SF-12 Physical Component Score

Variables Retained in Multivariate Models	Outcome Measures Analyzed			
	FEV ₁ % Predicted (n = 199)		SF-12 PCS (n = 199)	
	β	SE	β	SE
Dust, kitchen/living room floor per 100 mg	-0.2	0.5		
Dust, bed per 100 mg	-1.8*	0.6		
Dust mite allergen and specific IgE				
Dust mite specific IgE positive			3.4*	1.7
Dust mite allergen (log)			0.2	0.2
Dog allergen and specific IgE				
Dog owner	-9.7*	3.5		
Dog IgE positive	-6.7†	4.3		
Dog allergen (log)	0.5	0.7		
Cat allergen and specific IgE				
Cat owner	3.0	4.2		
Cat IgE positive	-5.0†	3.4		
Cat allergen (log)	-0.3	0.7		
IgE (Referent = IgE low for atopy)				
IgE equivocal (25–100 IU/L)	-3.8	3.3		
IgE probable (>100 IU/L)	-2.8	3.5		
Endotoxin (Referent = <25% quartile)				
25% to 50% quartile (>23, ≤42 EU/mg dust)	-5.4†	3.6		
50% to 75% quartile (>42, ≤70 EU/mg dust)	-1.5	3.6		
75% to 100% quartile (>70 EU/mg dust)	1.5	3.6		
Glucan (Referent = <25% quartile)				
25% to 50% quartile (>124, ≤211 µg/g dust)			-2.0	2.2
50% to 75% quartile (>211, ≤426 µg/g dust)			-2.4	2.2
75% to 100% quartile (>426 µg/g dust)			-1.5	2.2
Wall dampness (%)			-0.5†	0.3
Any houseplants			3.6†	2.1
Damp patches in living room or bedroom			-2.9	2.8
Mold visible in bathroom	-3.2	3.3	-0.5	2.2
Air filter	-4.2†	2.9	-3.3†	1.8
Heating (referent = other)				
Gas space heaters	5.4†	3.8	-1.3	2.4
Coal or wood heat	4.7†	3.6	3.1†	2.2
Bedroom air conditioner			-2.2	1.9
Bedroom humidifier (referent = none)				
Humidifier	1.7	6.3	2.5	4.0
Dehumidifier	13.2†	10.1	1.7	5.6
Any wall-to-wall carpet			2.7†	1.7

* $P < 0.05$; † $0.05 < P < 0.20$ FEV₁ % Predicted model $R^2 = 0.24$ ($P = 0.0001$); SF-12 PCS model $R^2 = 0.15$ ($P = 0.02$).

associated with the SF-12 PCS (in the direction of better health status, similar to its estimate in the simple model: 3.4 ± 1.7 ; $P = 0.04$). Re-testing these factors with asthma-specific QOL score as the dependent variable ($n = 168$ subjects after excluding those with rhinitis alone) yielded an $R^2 = 0.13$; $P = 0.16$). The only variable that was statistically significantly associated with QOL was heating with coal or wood (in the direction of better QOL; $-7.9 \pm$

3.3 points; $P = 0.02$). The IAQ variables alone, excluding dust mite and glucan, were associated with better explanatory power for QOL (study $n = 179$; $R^2 = 0.14$; $P = 0.02$).

Discussion

Multiple factors in the indoor environment can act independently or in concert to affect health outcomes among adults with asthma and rhinitis. Exposures linked to house dust

showed a moderate relationship to lung function and asthma severity, but a less prominent impact on general health status. In contrast, IAQ factors were related to general health status and to asthma-specific QOL. These responses can be characterized by a sum that is greater than its individual parts.

Our findings were also of interest in the factors having little explanatory power for the outcomes studied. Allergen exposure levels (including

dust mite) and dust mite sensitization were not associated with adverse effects. In prior studies among adults, dust mite exposure has had an inconsistent relationship to asthma outcomes.^{44,45} Index factors for indoor mold exposure, including dust glucan concentrations, damp or moldy walls, the number of houseplants, and increased humidity, were also not consistently associated with adverse effects. Indicators of indoor combustion byproducts also failed to demonstrate consistent negative effects.

A particular strength of this analysis is the broad range of potential risk factors that it includes. However, this range presents potential study limitations as well. We did not have an a priori model specifying a restricted set of predictor variables. We addressed this in two ways. First, we used a stepwise approach, placing a modest hurdle ($P < 0.20$) for entry in multivariate modeling. Second, we re-tested our multivariate models on different, but related outcomes (SAS for FEV₁ % predicted and asthma-specific QOL for SF-12 PCS).

Total IgE and specific IgE to cat, dog, and dust mite are examples of inter-related exposure variables that may not have retained strong individual associations in multivariate analysis, although they still contributed to the overall explanatory power of the models. Confounding with endotoxin or glucan did not seem to explain the adverse effect of dog ownership on lung function or SAS. Pet ownership and home endotoxin are known to be interrelated.^{46–48} We also found that both endotoxin and glucan levels were higher in the dog owners' homes in our study. Dog ownership, however, had a stronger and more consistent relationship to the outcomes studied than did either endotoxin or glucan, both in simple and multivariate models. Moreover, dog allergen concentrations in dust were unrelated to lung function and slightly protective in terms of SAS, suggesting that the

effect of dog ownership was not mediated through this mechanism.

The potential for exposure levels to be modified by disease severity itself poses a more difficult question. For example, if secondhand smoke exposure is selectively avoided by those with the most severe disease or the most symptoms from this source, this factor might actually appear to be "protective." The inability to selectively avoid such exposures may be an important characteristic differentiating the home indoor environment from the workplace indoor environment, which we did not analyze in this study. Thus, we cannot generalize our indoor environmental findings to work-related exposures even of the same or similar type.

Diagnostic heterogeneity also could have affected our study results. We believe that including adults with rhinitis together with adults with a range of asthma severity (many of whom also have concomitant rhinitis) is actually a strength of the study in that it better reflects the spectrum of asthma- and rhinitis-related airways disease among adults of this age range.

In summary, we found that multiple factors of the indoor home environment were associated with lung function, disease severity, health status and QOL in adults with asthma and rhinitis. Depending on the constellation of variables tested, approximately 10% to 20% of the variance of these outcome measures was accounted for by these factors. This clearly indicates a magnitude of effect that could be clinically relevant, in terms of measurable lung function and also in terms of perceived health and well-being.

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