

Evaluation of air and dust sampling schemes for Fel d 1, Der f 1, and Der p 1 allergens in homes in the Detroit area

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Background: Studies often use a point estimate of allergen exposure without fully justifying the accuracy of this single measure as an estimate of total exposure. Many studies have reported relationships between indoor allergen concentrations and manifestations of allergic disease on the basis of single samples.

Objectives: The purposes of this study were to (1) characterize the variability in dust and air concentrations of allergens, (2) assess the relationships between dust and air concentrations of allergens, and (3) determine the minimum number and timing of samples to characterize annual indoor allergen exposure.

Methods: As part of a prospective cohort study of asthma in children, air and dust samples were repeatedly obtained from the homes of children residing in suburban Detroit, Michigan. Concentrations of Fel d 1, Der f 1, and Der p 1 were measured in the samples. The results of various patterns of sampling were compared with yearly averages.

Results: The concentrations of all 3 allergens in both air and dust varied widely both within and between homes. The allergen concentrations had peak concentrations in the fall. There was little correlation between air and dust concentrations. Our results indicate that as few as 2 or 3 samples taken late in the year provide good estimates of the annual average concentrations.

Conclusions: Two or 3 samples, obtained 1 month apart and taken late in the year, represent the best balance between sampling effort and accuracy of the yearly exposure estimates of Fel d 1, Der f 1, and Der p 1 in temperate climates similar to those of Detroit, Michigan. (*J Allergy Clin Immunol* 1999;104:348-55.)

Key words: Der f 1, Der p 1, Fel d 1, correlation, sampling

A number of allergens have been associated with asthma, including dust mite, cat, and dog allergens.¹ There is a moderate amount of information available about airborne levels of dust mite allergen in homes,² with less reported

about air levels of cat and dog allergen.³⁻⁶ Each of these allergens have different physical properties (size and mass), which lead to different distributions in air and dust. For example, dust mite allergens (*Dermatophagoides farinae* [Der f 1] and *Dermatophagoides pteronyssinus* [Der p 1]) rapidly settle in air under undisturbed conditions,² whereas cat allergen (*Felis domesticus* [Fel d 1]) is known to stay suspended in the air for long periods of time.⁴ These differences in settling properties suggest that different sampling plans (eg, number, type, and frequency) might be required for an accurate estimate of potential allergen exposure in a study of atopic disease. Because some allergens vary seasonally, it is important to evaluate how well a limited number of samples represents the average annual exposure.

Previous studies examining these issues are limited.^{4,6,7} One study examined air and dust correlations of allergens in 30 homes, but only one pair of measurements was taken from each home.³ These investigators found a good correlation between air levels from different locations in a home (bedroom or living room), as well as between dust levels in different rooms, but a poorer correlation between air and dust levels for an allergen from the same room (bedroom or living room). The correlation of air to dust for Der p 1 in bedrooms was quite good (0.84) but poor in living rooms (0.18), and the correlation of air to dust for Der f 1 in bedrooms and living rooms was poor (0.37 and 0.06, respectively). Another study examined the year-to-year variation in dust mite antigen.⁸ Although this study included more than 1000 homes, only 2 samples were taken from each home, with the conclusion that mite antigen concentrations were stable over time.

In this study we investigated the relationships between the levels of Fel d 1, Der f 1, and Der p 1 in indoor air and dust. The data were analyzed to examine (1) the variability of measurements within a home, as well as the seasonality of these measurements; (2) the agreement between measurements of allergen levels in dust and air; and (3) the number and timing of measurements required to characterize annual allergen exposure.

METHODS

Design of the study

The data used in these analyses were collected as part of an ongoing study evaluating environmental determinants of allergic diseases in a population of children followed from birth. Selection of the study cohort has been previously described in detail.⁹ Briefly,

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all women 18 years and older with a prenatal appointment at one of 7 clinics serving the northern suburbs of Detroit, Michigan, were approached for study recruitment. To be eligible, a woman had to be a member of the Health Alliance Plan health maintenance organization and have an estimated date of confinement between April 15, 1987, and August 31, 1989, with delivery planned for one of 3 hospitals serving the health plan's members. Additionally, women had to reside within an area surrounding the clinics, as defined by contiguous zip codes. The area of interest included a broad cross-section of much of the northern suburbs of Detroit. All aspects of the study were approved by the Henry Ford Hospital Human Rights Committee, and written informed consent was obtained from all study participants.

A cohort of children with cord blood IgE concentrations of 0.56 IU/mL or greater was identified and followed up. As part of a comprehensive evaluation of each child's home environment, air and dust measurements were taken on a monthly basis for the first 2 years and every other month for the next 2 years. A total of 107 children were enrolled, with 91 children having a minimum of 6 and a maximum of 36 allergen measurements taken during the 4-year follow-up period of this study (ie, June 1987 to September 1991). All measurements were taken from the children's bedrooms. Three allergens were analyzed for the investigation: Fel d 1, Der f 1, and Der p 1.

Air and dust sampling

Air and dust samples were obtained from the children's bedrooms during monthly home visits. Dust samples were obtained by vacuuming a 1-m² area of floor directly beside the child's bed for 2 minutes with a small vacuum fitted with a sampling attachment³ (Sample Vac; Quan-Tec-Air, Inc, Minneapolis, Minn). The polyvinyl chloride sampling attachment is directly attached to the 4-inch flared vacuum nozzle. Dust is retained in the sampler by a polytetrafluoroethylene filter capable of retaining greater than 99% of particles larger than 0.1 μ m. After collection, dust samples were placed in a sealed plastic bag for transport, and the sampler was cleaned by washing before the next sample was taken. Air samples were obtained from the same room by using a volumetric air sampler (Air Sentinel, Quan-Tec-Air, Inc) and placed onto the same type of filters as used for dust samples. The air sampler was started shortly after the dust sample had been obtained and continued for 24 hours. The sampler was turned off by an automatic timer. The sampling volume was 86.4 m³ of air at a rate of approximately 1 L/sec.

Dust samples were separated, and the fine dust was weighed before extraction into PBS containing 0.1% Tween 20 and BSA at a 1:20 weight-to-volume ratio. Extracted samples were frozen until assay. The outer edges of the filters used to collect the air samples were trimmed, leaving only the area through which the air had passed. The polytetrafluoroethylene film containing the sample was then separated from the backing before being extracted overnight in 2 mL of the same buffer used to extract the dust samples. The samples were frozen until assay.

Both the air and dust samples were assayed for Der f 1, Der p 1, and Fel d 1 by using previously described mAb-based assays (Indoor Biotechnologies, Ltd, Chester, United Kingdom). Briefly, plastic microtiter plates were coated with appropriate mAbs (5H8 for Der p 1, 6A8 for Der f 1, or 6F9 for Fel d 1) in 50 mmol/L carbonate-bicarbonate buffer (pH 9.6) overnight. After coating, the plates were washed with PBS containing 0.05% Tween 20 and then incubated for 1 hour with PBS/Tween containing 2% BSA. Dilutions of the standards or the unknowns were then added to duplicate wells in 50- μ L aliquots and incubated overnight. After washing, the bound antigen was detected with biotin-labeled antibody, avidin-alkaline phosphatase, and phosphatase substrate (Sigma Chemical

Co, St Louis, Mo). The ranges of the standard curves were from 1 to 125 ng/mL for Der f 1 and Der p 1 and from 0.04 to 10 mU/mL for Fel d 1. The assay standards had been standardized at the University of Virginia by Dr Martin Chapman. Interassay coefficients of variation were typically under 12% for all 3 assays.

The units for dust measurements were micrograms per gram of dust for dust mites and milliunits per gram of dust for cat allergen. In the air the units are expressed as micrograms per 100 cubic meters of air for dust mites and milliunits per 100 cubic meters of air for cat allergen.

Statistical methods

A ratio estimator was used to calculate the percentage of detectable observations, as well as the average allergen concentration.¹⁰ The ratio estimation method treats each home as a cluster of observations and accounts for the sampling scheme in the estimation process. The values determined to be below the detectable limit for the 3 allergens were set at 0.04 mU/g and 0.0009 mU/100 m³ for Fel d 1 in the dust and air, respectively; 0.42 μ g/g and 0.01 μ g/100 m³ for Der f 1 in the dust and air; and 0.08 μ g/g and 0.002 μ g/100 m² for Der p 1 in the dust and air. On the basis of these limits, upper bounds for the average concentrations for the 3 allergens were estimated. To describe the variability in the allergen concentrations within a home, the range (maximum value minus minimum value) was computed for each home. Summary statistics, including the median, maximum, and minimum range, were computed across all houses. To assess whether the allergen levels displayed a seasonal pattern, a plot of the average of all allergen measures falling in a particular month was constructed for both dust and air measurements.

The correlations between air and dust concentrations for Fel d 1, Der f 1, and Der p 1 were estimated by using 2 approaches. First, a correlation between air and dust concentrations within each house was estimated. This correlation describes the relationship between air and dust levels measured at the same time. A high value would indicate that high dust concentrations occurred simultaneously with high air concentrations. A low value would imply that dust concentrations were unrelated to the corresponding air concentrations within a particular household. Spearman rank order correlations are used instead of Pearson correlations because the data had a substantial number of observations below the detectable limit. This nonparametric approach assumed that these values were all tied at the minimum level. Additionally, the allergen concentrations varied widely with extremely high values, which could have strongly influenced estimation of the Pearson correlation. The influence of either extreme values or a number of tied observations at the minimum value on estimation of a Spearman correlation is minimal.

The second approach to evaluating air and dust correlations generated an ordered pair of average concentrations for each allergen for each house. The average concentration for each allergen was the mean value of all measured values through the first 4 years. Thus there were 4-year average values for each allergen in air and dust for each house. A Spearman correlation was then generated, correlating the average air and dust values for each allergen for all houses. A high value would indicate that houses with high average dust allergen levels tended to have high average air allergen levels. The use of an average value minimized the impact of the high day-to-day variability in allergen concentrations.

A Spearman correlation analysis was again used to examine various systematic sampling schemes to see how strongly they were associated with the average allergen concentration over a 1-year period. To identify the best number and timing of sampling, 6 different approaches were examined. First was the approach of taking a single observation at random during the year. Because 2 years of monthly data were available, a single observation from year 1

TABLE I. Descriptive statistics of allergen concentrations measured prospectively in air and in dust from 91 houses

Allergen	Observations	Percent detectable		Mean concentration		Range of concentrations within a household		
		%	SEM	Mean	SEM	Median	Minimum	Maximum
Fel d 1, dust (mU/g)	31.9	90.8	0.8	10.23	3.58	13.24	1.21	959.79
Fel d 1, air (mU/100 m ³)	31.7	78.0	1.7	15.02	5.87	6.67	1.08	1879.51
Der f 1, dust (μg/g)	31.9	68.3	2.6	5.62	0.78	19.93	0.48	188.48
Der f 1, air (μg/100 m ³)	32.1	25.4	2.0	0.97	0.11	5.78	0.00	28.85
Der p 1, dust (μg/g)	31.8	73.2	2.0	2.02	0.34	5.69	0.20	231.92
Der p 1, air (μg/100 m ³)	31.9	23.9	1.7	2.07	0.25	11.85	0.00	129.68

was selected at random and averaged with a single observation from year 2. This average was correlated to the average household allergen concentration for all observations during years 1 and 2 of study. This procedure was repeated 100 times, and the distributional properties of the "random pick" Spearman correlation were described.

The second approach was a systematic sampling scheme involving the measurement of allergen concentrations sampled in a particular month. Again, because 2 years of monthly data were available, the average of the 2 observations taken in a particular month, one from each year, was correlated against the 2-year average allergen concentration. These correlations were evaluated for each of the 12 months.

The other scenarios involved sampling in 2 consecutive months, in each of 2 months separated by 6 months, one from each of 3 consecutive months, and sampling quarterly over a year's time. These schemes were all evaluated for the 2 years of data, as outlined above, averaging the samples from years 1 and 2. All possible monthly combinations were evaluated, which included 12 for 2 consecutive observations (January-February, December-January), 6 for 2 separate observations (January-July and June-December), 12 for 3 consecutive observations (January-February-March, December-January-February), and 4 for 3 separate observations (January-May-September, April-August-December).

Each allergen concentration was evaluated separately. To identify the "best" strategy for sampling, the correlations for a particular sampling scheme for the 3 allergens, evaluated in both air and dust, were averaged. High averages were used to identify the best approach.

All analyses of Fel d 1 ignore the presence or absence of cats in the home. The purpose of the analyses was to provide an optimal sampling scheme that could be easily implemented in a community setting. It was hoped that the sampling plan identified would be applicable to all houses independent of cat ownership.

RESULTS

The descriptive statistics for the 3 allergens measured both in the dust and in the air are summarized in Table I. The 91 homes with at least 6 separate allergen measurements taken had an average of 32 measurements each. This represents 89% of the 36 measurements planned for in the protocol.

As expected, allergens measured in the air had more measurements below the level of detectability for the assay than allergens measured in the dust. The percent of measurements detectable for Fel d 1 in the air is 78.0% compared with 90.8% in dust. For dust mites, the percentage of detectable measurements was lower than that for cat allergen in both air and dust. Der f 1 had only

25.4% detectable in the air compared with 68.3% detectable in the dust. The estimates were similar for Der p 1, with 23.9% detectable in the air and 73.2% detectable in the dust.

Mean values of cat allergen concentrations were 10.23 ± 3.58 mU/g (mean $\pm$ SEM) for Fel d 1 in the dust and 15.02 ± 5.87 mU/100 m³ for Fel d 1 in the air. The average Der f 1 in the dust was 5.62 ± 0.78 μg/g, with the average in the air at 0.97 ± 0.11 μg/100 m³. Der p 1 had an average concentration in the dust of 2.02 ± 0.34 μg/g and an average concentration of 2.07 ± 0.25 μg/100 m³ in the air.

The high variability of measurements within a household is demonstrated by the range of concentrations (Table I). The median range for Fel d 1 as measured in the dust was 13.24 mU/g, with a maximum observed value of 959.8 mU/g. The median value for dust concentrations of Fel d 1 is 3.8 times the magnitude of the standard deviation and is greater than the mean for all homes. In air, Fel d 1 had a median range of 6.67 mU/100 m³, with a maximum value of 1879.5 mU/100 m³.

The results are more extreme for dust mite allergen. Der f 1 had a median range of 19.93 μg/g in the dust and 5.78 μg/100 m³ in the air. These median range values both exceeded the mean concentration by 2-fold and the standard deviation by more than 20-fold. The same is true for the range of concentrations for Der p 1. The median range for Der p 1 was 5.69 μg/g for dust and 11.85 μg/100 m³ for air.

Part of the reason for the large range in values within each home is seasonal variation in allergen levels. Fig 1 shows the seasonal patterns of the allergen values across the year in both dust and air concentrations. Fel d 1 shows a maximum in fall (dust) and early spring (air), with minimums in July and August. The 2 dust mites follow similar patterns, with peaks in the fall and lower values in the spring.

The correlations comparing the allergen concentrations in the air with simultaneously collected allergen concentrations in the dust are uniformly low. These home-specific correlations are averaged, and the average correlations are 20 ± 22 (mean $\pm$ SD) for Fel d 1, 13 ± 22 for Der f 1, and 9 ± 23 for Der p 1.

Household means were also correlated. Mean allergen concentrations measured in the air were correlated to mean allergen concentrations measured in the dust for the same home. The correlation was computed on the 91

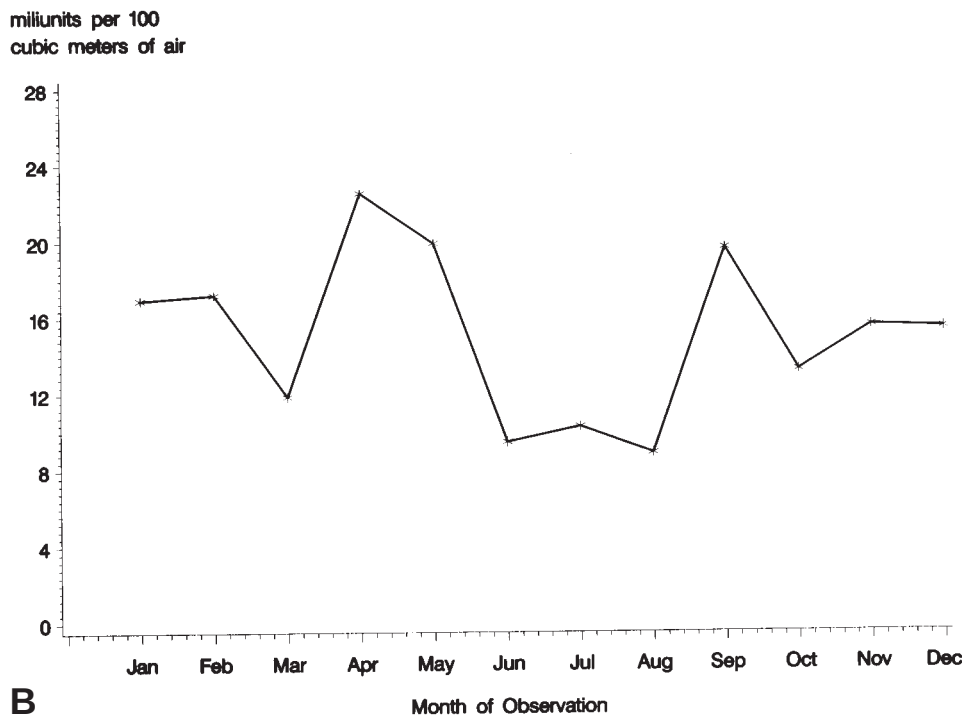
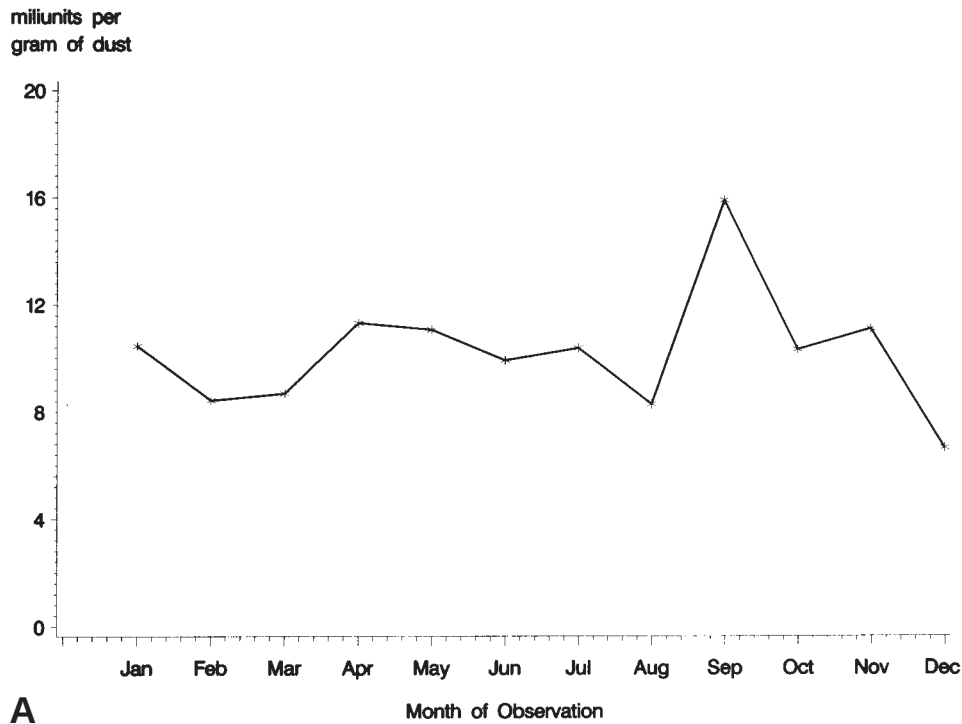
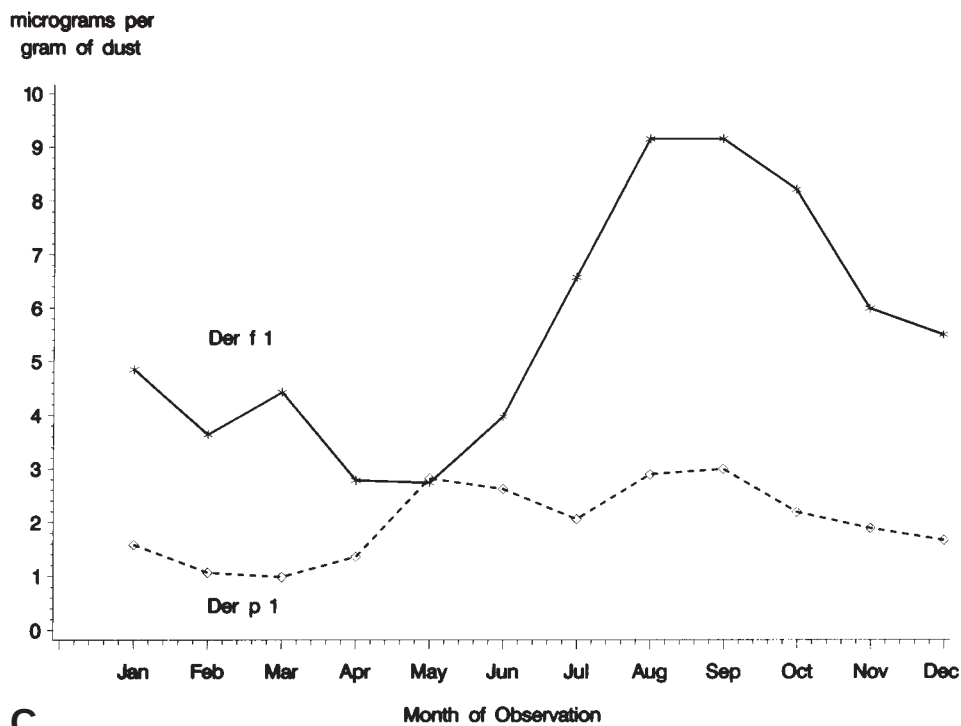


FIG 1. A, Fel d 1 concentrations measured in dust. B, Fel d 1 concentrations measured in air. C, Dust mite concentrations measured in dust. D, Dust mite concentrations measured in air.

ordered pairs, one from each home, and is estimated at 66 for Fel d 1, 48 for Der f 1, and 37 for Der p 1.

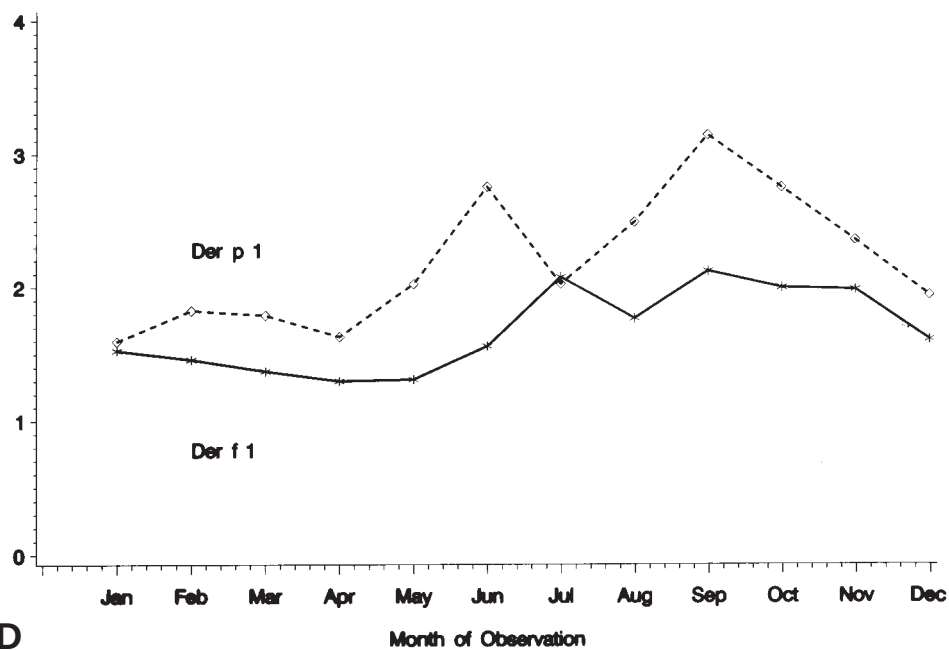
Considering the evaluation of sampling schemes, the average correlation between the mean of 2 randomly chosen observations, one selected any time during the first

year of study and the second selected any time during the second year of study, to the 2-year average allergen concentration is summarized below. The mean correlation varied from a low of 47.9 ± 7.6 for Der p 1 in air to a high of 78.6 ± 3.9 for Der f 1 in dust. The average correlation for



C

micrograms per 100
cubic meters of air



D

FIG 1. CONT.

cat allergen was higher in air (71.1 ± 5.1) than in dust (62.6 ± 6.0). The reverse was true for dust mites, with the average dust correlations higher for Der f 1 (78.6 ± 3.9) and Der p 1 (72.0 ± 4.8) than the average air correlations for Der f 1 (48.6 ± 7.3) and Der p 1 (47.9 ± 7.6), respectively.

The maximum correlations observed for the remaining 5 systematic sampling schemes are summarized in Table II. In all cases the maximum observed correlation for a single observation in a preselected month was larger than the mean observed correlation for a randomly chosen sin-

TABLE II. Maximum Spearman correlations for 5 systematic sampling schemes

Allergens	Sampling schemes				
	One observation	Two consecutive observations	Two separate observations	Three consecutive observations	Three separate observations
Fel d 1 (dust)	68 (Sep)	76 (May, June)	78 (May, Nov)	81 (Sep, Oct, Nov)	82 (Mar, July, Nov)
	68 (May)	71 (June, July)	74 (June, Dec)	77 (Mar, Apr, May)	79 (Jan, May, Sep)
	67 (Nov)	70 (Oct, Nov)	73 (Mar, Sep)	76 (Apr, May, June)	77 (Feb, June, Oct)
Fel d 1 (air)	80 (May)	86 (Apr, May)	87 (June, Dec)	89 (Apr, May, June)	91 (Apr, Aug, Dec)
	80 (Dec)	83 (Jan, Feb)	86 (Apr, Oct)	89 (Dec, Jan, Feb)	86 (Feb, June, Oct)
	79 (Feb)	82 (Nov, Dec)	78 (May, Nov)	88 (Nov, Dec, Jan)	84 (May, Sep, Oct)
Der f 1 (dust)	87 (Oct)	88 (Nov, Dec)	88 (Mar, Sep)	93 (Sep, Oct, Nov)	95 (Feb, June, Oct)
	84 (Sep)	88 (Sep, Oct)	85 (June, Dec)	93 (Oct, Nov, Dec)	94 (Jan, Mar, Sep)
	82 (Nov)	86 (Oct, Nov)	84 (May, Nov)	91 (Aug, Sep, Oct)	89 (Mar, July, Nov)
Der f 1 (air)	82 (Jan)				
	73 (Oct)	71 (Sep, Oct)	73 (June, Oct)	83 (Aug, Sep, Oct)	79 (Feb, June, Oct)
	61 (Nov)	71 (Oct, Nov)	72 (Feb, Aug)	81 (Sep, Oct, Nov)	76 (Apr, Aug, Dec)
Der p 1 (dust)	61 (Aug)	65 (Nov, Dec)	64 (May, Nov)	80 (Oct, Nov, Dec)	70 (May, Sep, Oct)
	82 (Dec)	82 (Sep, Oct)	81 (Mar, Sep)	90 (Aug, Sep, Oct)	92 (Apr, Aug, Dec)
	76 (Oct)	80 (Oct, Nov)	79 (Apr, Oct)	90 (Oct, Nov, Dec)	88 (Jan, May, Sep)
Der p 1 (air)	75 (Jan)	80 (Nov, Dec)	76 (May, Nov)	89 (Sep, Oct, Nov)	87 (Feb, June, Oct)
	59 (Nov)	60 (Oct, Nov)	68 (May, Nov)	72 (Nov, Dec, Jan)	79 (Feb, June, Oct)
	58 (Oct)	59 (Nov, Dec)	64 (Apr, Oct)	70 (Oct, Nov, Dec)	75 (Mar, July, Nov)
	50 (Jun)	55 (Apr, May)	56 (June, Dec)	69 (Sep, Oct, Nov)	71 (Apr, Aug, Dec)
	50 (Feb)				

TABLE III. Best overall correlation with the average yearly concentrations by sampling methods

Sampling methods	Overall average		Dust average		Air average	
	Correlation	Time	Correlation	Time	Correlation	Time
One sample	71.3	Oct	76.0	Oct	66.7	Oct
	67.8	Nov	74.3	Sep	62.7	Nov
	65.2	Dec	74.0	Dec	58.0	Feb
Two consecutive samples	73.8	Oct, Nov	79.3	Sep, Oct	69.0	Oct, Nov
	72.8	Nov, Dec	78.7	Oct, Nov	68.7	Nov, Dec
	71.2	Sep, Oct	77.0	Nov, Dec	65.0	Jan, Feb
Two separated samples	75.3	Apr, Oct	80.7	Mar, Sep	74.7	Apr, Oct
	74.7	May, Nov	79.3	May, Nov	70.0	May, Nov
	72.0	June, Dec	78.3	June, Dec	67.0	Feb, Aug
Three consecutive samples	82.3	Sep, Oct, Nov	87.7	Sep, Oct, Nov	78.7	Oct, Nov, Dec
	82.3	Oct, Nov, Dec	86.0	Oct, Nov, Dec	77.0	Sep, Oct, Nov
	79.3	Aug, Sep, Oct	84.7	Aug, Sep, Oct	75.7	Nov, Dec, Jan
Three separated samples	83.3	Feb, June, Oct	87.0	Jan, May, Sep	80.3	Feb, June, Oct
	82.7	Apr, Aug, Dec	86.3	Feb, June, Oct	80.3	Apr, Aug, Dec
	79.2	Jan, May, Sep	85.0	Apr, Aug, Dec	74.3	Mar, July, Nov

gle observation. The preselected months with the best correlations are generally fall months (September, October, and November).

The maximum observed correlation for 2 consecutive observations is close to that observed for 2 observations separated by 6 months. The Fel d 1 level in dust has a maximum correlation of 76 for the May-June sampling frame and 78 for the May-November sampling frame. In the air Fel d 1's maximum correlation is 86 for April-May and 87 for June-December. The dust mites are more consistent with the consecutive sampling plan showing maximums in September-October for Der f 1 in the dust ($r = 88$), Der f 1 in the air ($r = 71$), and Der p 1 in the dust ($r = 82$). Der p 1 in the air has a maximum correlation of 60 in October-November. The separated sampling pattern

has similar maximum correlations, with Der f 1 in the dust having a correlation 88 in March-September, Der f 1 in the air at 73 in June-October, Der p 1 in the dust at 81 in March-September, and Der p 1 in the air at 68 in May-November.

The pattern for 3 observations is analogous to that described above for 2 observations. The addition of a third observation improves the maximum observed correlation for all 3 allergens. Late fall is again the time during which maximum correlations are observed.

The best sampling plan is defined as that which maximizes the average correlation resulting from the 3 allergens. Table III evaluates this rule for air concentrations alone, dust concentrations alone, and the combined air and dust allergen concentrations. Three samples, either

consecutive or separated, provide the highest correlations. The overall average correlation of 82.3 was observed for sampling late in the fall (September, October, and November), which was consistent for both air and dust. With 2 consecutive observations, the maximum average correlation was 73.8 for October-November.

DISCUSSION

Compared with cat allergen, dust mite allergens become airborne on larger particles (ie, >10 nm), which settle out of the air in undisturbed conditions in 20 to 30 minutes.^{5,11,12} Cat allergen is airborne primarily on much smaller particles (ie, <2 nm), which may remain in the air for longer periods of time.⁴ Our data is consistent with these properties, showing a higher percentage of detectability in the air for Fel d 1 than for either of the dust mite allergens considered. It also follows that the percentage detectable in the dust would be higher, which is what we observed.

The variability of the data, as characterized by either the standard error of the mean concentration or the average range of the observations, is high. This suggests that a single observation would be inadequate to accurately represent the average allergen burden of a home. This is further supported by the observed seasonal trends in the allergen levels.

Our assessment of seasonal trends in the 3 allergens considered has the strength of being based on 4 years of data and up to 36 observations per home. The study by Chan-Yeung¹³ examined seasonal variation on the basis of one measurement from each of 4 seasons over a single year. This study observed an association with season and dust mite level. Platts-Mills et al² examined 12 houses in central Virginia on a monthly basis for 1 year. A definite seasonal trend in dust mites was noted, with the highest values occurring in August through December. Both of these studies are in agreement with the seasonal trends we observed.

A number of investigators have reported on relationships between various housing factors and antigen levels. In many of these studies the antigen determinations were based on a single visit to the home.¹⁴⁻¹⁶ Our results indicate a high degree of variability in allergen concentrations over time within a household. This, coupled with the seasonal variation of the allergen levels, would suggest that reports that associate housing characteristics or even health effects with antigen measurements taken from a home at a single point may be biased by incorrect estimates of allergen exposure.

An important design issue in epidemiologic studies of respiratory diseases is how best to sample allergen exposure. Intuitively, air measurements would be the ideal standard, but in reality dust samples are often used. The household correlations between air and dust allergen concentrations were small, indicating a weak relationship between dust and air measurements taken concurrently.

Other investigations that have examined air-to-dust correlations have observed some high correlations. These

results have been inconsistent and are based on much smaller sample sizes. The study by Swanson et al³ found an air-to-dust correlation for Der p 1 of 0.84 but only small-to-moderate correlations for Der f 1 and Fel d 1. Thirty houses were examined, but just 2 pairs of observations were taken from each home. Sakaguchi et al⁶ analyzed 4 pairs of measurements per home but included only 13 homes. Both dust mite correlations were small, but Fel d 1 had an air-to-dust correlation of 0.88. The study by Munir,¹⁴ which examined 123 households, had a single dust measurement and a single air measurement in a subset of 20 homes. The correlation for Fel d 1 was less than 0.30.

The correlations of household means were somewhat larger. This indicates that on average houses with high allergen levels measured in the dust tended to also have high allergen levels measured in the air. The correlations were still moderate, however, with dust concentrations accounting for at most 44% of the variability in the air concentrations (for Fel d 1).

The lack of a strong linear association between the concentration of allergens measured in the air and that of allergens measured in the dust suggests that both sampling procedures should be used. The values are different enough that the inference relating allergen level to an outcome could be different based on the sampling location of allergen.

A single observation of an allergen level gathered at convenience over the data accrual period is the simplest sampling plan to implement. However, our data show that the association of the single randomly gathered allergen level with the yearly average allergen level is inferior to more systematic sampling plans. In our geographic setting, a single observation sampled in October or November shows a higher correlation with the yearly average than does the single randomly sampled observation. This is true for the 3 allergens gathered either in the air or in the dust.

When sampling multiple times, it appears that sampling sequentially (ie, once per month on consecutive months) over time yields similar results to sampling once per month with the months equally spaced. Three sequential samples demonstrate the highest average correlation for the 3 allergens gathered in the air. For sampling in the dust, 3 observations have a higher average correlation, but the difference is less marked. Sampling in air or dust shows consistency as to the time of year when sampling should be done. The highest average correlations occur late in the year, with October and November or September and October being optimal for 2 samples and September through November or October through December being optimal for 3 samples.

To our knowledge, these results provide the most comprehensive evaluation of allergen levels in homes to date. Not only have we taken the largest number of samples from each home over time, but we also took samples directly from air, as well as from dust. Our results are limited to suburban homes in a temperate climate with moderate humidity.

The data demonstrated large variability in all 3 allergens considered both in the dust and in the air. Within a household, the range of values for any particular allergen varied widely. Seasonality of the allergen levels was also demonstrated, with higher values in late fall. The correlations between air and dust measurements for all 3 allergens were small, indicating poor agreement between these 2 concentrations. This suggests a single sample will be inadequate and that both air and dust measures must be evaluated. A limitation is the substantial number of air measurements for dust mites that were nondetectable.

Our results indicate that a fairly good representation of the annual average exposure may be obtained with as few as 3 or even 2 samples taken late in the year. Two samples seemed adequate for allergen measures in dust, whereas 3 were superior for allergen measured in the air. Until more is known about the relationship and mechanism between allergen exposure and disease outcomes, we would recommend a prudent sampling scheme to include 2 or 3 measurements from both dust and air for all allergens considered (Fel d 1, Der f 1, and Der p 1). These measurements should be spaced a month apart and taken late in the year. These results are applicable to climates similar to the Detroit area and apply only to the 3 allergens considered in this report.

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