Airborne Cat Allergen (*Fel d* I)[1-3]

43

Environmental Control with the Cat *In Situ*

FREDERIC DE BLAY,[4] MARTIN D. CHAPMAN, and THOMAS A. E. PLATTS-MILLS

SUMMARY In a house with a cat furnishings, air-exchange rate, and the cat are all thought to influence airborne cat allergen. We carried out experiments using two separate rooms, modifying the environment, applying different cleaning techniques, and washing the cat, to analyze these sources and to design methods of reducing airborne allergen. Airborne measurements were made with a cascade impactor and a two-site monoclonal antibody-based immunometric assay for cat allergen *Fel d* I. Within 30 min of entering a 30-m³ clean room the cat itself was found to increase airborne *Fel d* I by 30 to 90 ng/m³. Following serial weekly washing of the cat this increase was reduced to ⩽ 7 ng/m³, with a more marked fall in small particles (⩽ 2.5 μm diameter) from 9.5 to ⩽ 0.4 ng/m³. To study the influence of the room design we kept the cat in a room of 33 m³ for 20 h/day and modified the room. This room was studied with or without furnishings and with air-exchange rates of 0.2 or 2.4 air changes per hour. Both low ventilation rate and furnishings increased the level of *Fel d* I measured 1 h after the cat was removed. However, the most striking finding was that the carpet accumulates cat allergen at ~100 times the level for a polished floor, that is, ~100 μg/day *Fel d* I compared with ~0.5 μg/day *Fel d* I. In keeping with this air filtration was effective at cleaning the air only if (1) there was no carpet and (2) the floor was cleaned first. The results show that airborne cat allergen can be dramatically reduced by a combination of washing the cat, reducing furnishings, vacuum cleaning, and air filtration. Comparison with previous results suggests that the reductions achieved may be sufficient to allow a cat-sensitive patient to live safely in the same house as a cat.

AM REV RESPIR DIS 1991; 143:1334-1339

Introduction

Surveys of the United States suggest that at least 2% of the population are allergic to cats, and from questionnaire answers it appears that approximately one third of these individuals live in a house with a cat (1, 2). Furthermore, it is now clear that cat allergy is common among asthmatic patients in clinic populations and also a significant risk factor for emergency room visits with asthma (3). Controlling exposure to cat allergens is therefore important both in managing symptomatic allergic individuals and potentially in reducing the risk of sensitization. Almost all approaches to controlling airborne cat allergen have focused on persuading the patients to get rid of cats. However, a recent report has confirmed that repeated washing of cats not only removes allergen from the cat but also leads to progressive reductions in the quantity of allergen accumulating on the cat (4, 5).

Previous experiments have shown that the major cat allergen (*Fel d* I) remains airborne in undisturbed conditions and that a significant proportion is associated with particles less than 2.5 μm in diameter (6-9). It is likely that these properties are responsible for the distinctive rapid onset of symptoms experienced by patients who are allergic to cats. This is in striking contrast to dust mite allergens, with which a rapid onset of symptoms on entering a house is unusual and airborne allergen is associated with large particles that fall rapidly (7, 10). Our previous results studying airborne cat allergen in houses with cats suggested that both increased furnishings and low air-exchange rates played a significant role in increasing airborne cat allergen (9). However, it is clear that the cat itself contributes to airborne allergen (8, 11, 12). The present studies used established monitoring techniques and an experimental room to define more closely the contributions of furnishings, ventilation, and the cat itself. The results demonstrate that the cat can generate high levels of airborne allergen and that weekly washing of the cat dramatically reduces the contribution of the cat to airborne allergen. In the absence of the cat, airborne cat allergen appears to be maintained by resuspension of particles from reservoirs within the room (including carpets and sofas). The results suggest that in an uncarpeted room the combination of vacuum cleaning, air filtration, and washing the cat can reduce airborne cat allergen by ⩾ 90 %.

Methods

Air sampling was carried out using a Cassella Mark II cascade impactor (Cassella, London, UK) as described previously (9, 10, 13, 14). The four stages of the cascade impactor were loaded with 2.5-cm glass disks (T13206; Cassella) coated with 5% agarose-sorbitol gel (5 g agarose, MCB AX05 17-3; 50 g D-sorbitol, (S1876; Sigma Chemical Corp., St. Louis, MO) in 100 ml borate-buffered saline, pH 8.0). A glass fiber filter was run in parallel at the same flow rate to collect total airborne particles. The cascade impactor and the parallel filter were connected via a flow meter (British Oxygen Company, Boreham Wood, UK) to a vacuum pump. Air was sampled for periods of up to 1 h at flow rates of between 17.5 and 19 L/min. The agarose-sorbitol gel was removed from the disks and eluted in 0.5 ml 1% bovine serum albumin (BSA), phosphate-buffered saline (PBS), and 0.05% Tween* 20 (assay buffer, BSA-PBS-Tween) overnight at 4° C. As in our previous report (9), the results for the fourth stage of the cascade impactor were combined with the results for the final filter and expressed as particles ⩽ 2.5 μm in diameter. The eluate from the glass fiber filters was collected in 1 ml buffer by compressing the filters in a 3-ml plastic syringe.

(Received in original form May 29, 1990 and in revised form November 8, 1990)

[1] From the Department of Medicine, University of Virginia, Charlottesville, VA.

[2] Supported by Grant No. AI-20565 from the National Institute of Allergy and Infectious Diseases and by the Virginia Center for Innovative Technology.

[3] Correspondence and requests for reprints should be addressed to Frederic de Blay, Pavillon Laennec, Hospices Civils de Strasbourg, 1, Place de l'Hôpital, 67000 Strasbourg, France.

[4] Supported by a Fulbright Scholarship 1989, courtesy Glaxo, Inc., and by the UCB Institute of Allergy Fellowship.

Monoclonal Antibody (MAb) ELISA for Fel d *I*

The assay used here to measure *Fel d* I was a two site MAb-based ELISA. It was similar to that described for the major dust mite allergens (15), but using MAbs specific for two different epitopes on *Fel d* I (Fd1A and Fd1B) (16, 17). Immulon® 2 flat-bottomed ELISA plates (Dynatech, Alexandria, VA) were coated with 10 µg/ml of 6F9 anti-Fd1B MAb in 0.05 M carbonate-bicarbonate buffer, pH 9.6, overnight at 4° C. The plates were washed twice with PBS-Tween and blocked for 1 h with 1% BSA-PBS-Tween (assay buffer). After a further two washes 100-µl aliquots of either cat allergen standard or eluates from the cascade impactor, dust, or pelt extract were added to the wells and incubated for 1 h at room temperature. The plates were washed with PBS-Tween five times, and 100 µl biotinylated 3E4 anti-Fd1A MAb was added to each well and incubated for a further hour. After five washes 100 µl streptavidin peroxidase (0.25 µg/ml; Sigma) was added and incubated for 30 min. The plates were washed a final five times and developed with 100 µl 0.01 M ABTS (Sigma) in 0.07 M citrate phosphate. The standard used for the assay was OBRR, FDA cat E3, which contains 10.5 units/ml *Fel d* I. (We have estimated that 1 unit = 4 µg *Fel d* I [17].) A control curve for each assay was established using the range 0.16 to 84 ng/ml *Fel d* I.

Room Description and Design of the Experiments

The experiments were performed over 146 days in a 33-m³ room located in a 20-yr-old suburban second-floor apartment. The experiment began at the same time as the cat arrived in the apartment. The room had one door, one 1.20 × 0.75 m window, and a fitted synthetic carpet of 12 m² with a pile depth of 2.0 cm.

The cat was a 2-yr-old male. It spent a mean time of 20.1 ± 2 h/day free in the room. The door of the experimental room was always closed even when the cat was out of it. Airborne cat allergen was measured either in the unfurnished (for 67 days) or in the furnished room (for 79 days). Unfurnished conditions were obtained by covering the carpet with hardboard and plastic sheeting and adding a metal chair. In furnished conditions the hardboard and plastic film were removed and an armchair covered with a synthetic sheet was added, which was initially free of *Fel d* I. During the experiments water, food, and cat litter were located in the room.

Ventilation rate was increased by opening the window and by running a 20-inch-diameter domestic fan (Toastmaster® 20 inch-4433; Toastmaster Inc., Boonville, MO) 3.5 m from the window placed 70 cm above the floor. Airborne measurements were performed in the room with ventilation rates of 0.2 and 2.4 air changes per hour (ACH). The air-exchange rate was measured using a multizone tracer gas technique (Environmental Chemistry Laboratory, NAHB National Research Center, Upper Marlboro, MD), Airborne *Fel d* I was monitored before and after using a HEPA filter air cleaner (Enviracaire, Hagerstown, MD) and a HEPA filter vacuum cleaner (Model GS90; Nilfisk Inc., Malvern, PA). To study the short-term effects of the cat on airborne *Fel d* I, we used a separate room of 30 m³ located in a house without a cat (clean room). The air sampling was performed during the first 30 min after the cat entered the room with the cat unwashed or immediately after washing. Before each experiment the air of this room was cleaned using a HEPA air cleaner (Enviracaire) with a flow rate of 400 m³/h, and a background sample was then performed over the 30 min before the cat entered the room.

Dander Collected in the Floor Dust or During Cat Brushing

The plastic sheeting covering the hardboard was incubated in 9 L of borate buffer saline (BBS) overnight at 4° C. This buffer was then assayed for *Fel d* I. The cat was thoroughly brushed for 3 min on four occasions; the interval between brushings varied from 7 days to 2 wk. The cat brush was incubated directly in 650 ml BBS overnight at 4° C. Between uses, the brush was washed with water and methanol; after this procedure elution of the brush with 650 ml of BBS contained no detectable *Fel d* I (< 0.2 ng/ml). The cat was bathed without anesthesia with 1 L of distilled water. The bath water was lyophilized and resuspended in BSA-PBS- Tween.

Results

Airborne Cat Allergen in the Presence of the Cat

The effect of the cat was measured both in the experimental room with no furnishings and also in a "clean" room with no background. In both situations the cat increased airborne allergen on average by 60 ng/m³ (range 30 to 90 ng/m³; figure 1 and table 1). The particle size of allergen was analyzed in the clean room. Although the room was tight (window and central heating duct closed), the proportion of *Fel d* I associated with small particles (14%) was comparable to that found in the experimental room in unfurnished conditions with a high air-exchange rate. In the same room air sampling was performed with the cat wrapped in plastic sheeting so that only its head was exposed (table 1). The results suggest that the cat's breathing produced less than 10% of the allergen becoming airborne from the cat.

Effect of Washing the Cat on Airborne Cat Allergen and Production of Cat Allergen

The cat was bathed weekly for 4 wk with 1 L distilled water. The effect of the cat on airborne allergen was measured the day before and immediately after the bath (figure 1). Over the first 2 wk the increase in airborne *Fel d* I caused by the cat decreased from 60 to 7.7 ng/m³ before the third bath. The total amount of *Fel d* I collected in the water used for washing the cat dropped progressively from 440 µg in the first wash to 40 µg in the fourth wash. In keeping with the decreased quantities of allergen removed from the cat the effect of washing on the airborne *Fel d* I produced by the cat decreased progressively over 4 wk (see figure 1). These results show a good correlation between the effect of the cat on airborne *Fel d* I and the amount of *Fel d* I that can be washed from the cat. Surprisingly, the cat showed rather modest reaccumulation of *Fel d* I between washes.

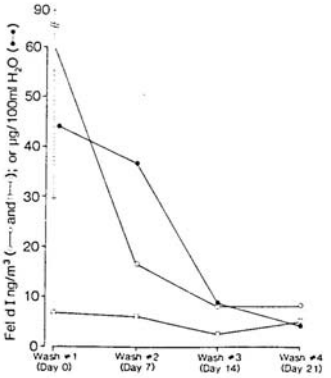


Fig. 1. Effect of washing the cat on airborne cat allergen: Airborne *Fel d* I concentrations (ng/m³) measured immediately before the cat was washed (*open circles*) and during the 30 min after washing the cat (*open squares*). Total amount of *Fel d* I collected in the cat wash (µg *Fel d* I)/100 ml H_2O (*closed circles*). The range of values recorded for increase in airborne *Fel d* I when the cat entered a room is also shown by the vertical dashed bar (n = 8).

Measurement of Fel d *I Collected in Floor Dust or Obtained by Brushing the Cat*

After the cat had been present in the room for 67 days on plastic sheeting, collecting the dust on the sheeting yielded only 32 µg *Fel d* I. This represents a rate of accumulation of 480 ng/day *Fel d* I. This result was comparable to those obtained by measuring *Fel d* I in four cat brushings spaced 1 to 2 wk apart; 427 ± 63 ng *Fel d* I per brushing. However, when the cat lived in the room with a carpet for 79 days the quantity of *Fel d* I

TABLE 1

AIRBORNE *Fel d* I PRODUCED BY THE CAT ENTERING A ROOM; UNRESTRAINED, WRAPPED IN PLASTIC SHEETING OR AFTER WASHING

Particle Size (μm)	Stages	Baseline,* n = 7 (ng/m³)	Cat Present,† n = 3 (ng/m³)	(%)	Cat Wrapped in Plastic Sheeting, n = 3‡ (ng/m³)	(%)	After§ Third Washing (ng/m³)	(%)
⩾ 6–20	I	< 0.2	36.0	60	3.6	85	1.9	63
2–15	II	< 0.2	13.0	21	< 0.2	< 5	0.7	25
1–5	III	< 0.2	2.5	4	< 0.2	< 5	< 0.2	6
< 2.5	IV + final filter	< 0.2	7.0	14	< 0.2	< 5	< 0.2	6
Total		< 0.2	59		4.2		3	
Parallel filter		< 0.2	66		—		2.6	

* Sampling for 30 min.
† Sampling during the first 30 min after the cat entered the room.
‡ Sampling for 20 min, cat's head 30 cm from the intake orifice of the cascade impactor. In this experiment a parallel filter control was not possible.
§ Sampling was carried out with the cat free in the room for 30 min; this experiment was carried out only once.

in the carpet dust increased from very low values (~5 ng/g dust) at the beginning of the experiment to 570 μg/g *Fel d* I of dust after 79 days. Repeated vacuum cleaning of this carpet over 15 min recovered a total 30 g dust, which yielded 15 g after sieving. Thus, the minimum estimate of accumulated *Fel d* I was 8.5 mg (15 g at 570 μg/g), which represents a rate of accumulation of 107 μg *Fel d* I per day. It appeared that the rate of accumulation of allergen was at least 100 times higher in the carpet than on the plastic sheeting. Presumably, this represents primarily the ability of the carpet to retain particles carrying cat allergen but also could indicate that allergen is rubbed off the cat by the carpet.

TABLE 2

EFFECT OF AIR EXCHANGE AND THE PRESENCE OF FURNITURE ON PARTICLE SIZE DISTRIBUTION OF AIRBORNE *Fel d* I IN A 33-m³ ROOM 1 H AFTER CAT REMOVAL

ACH*	Unfurnished (ng/m³)	Furnished (ng/m³)
0.2		
Total airborne on the parallel filter†	13.5 (n = 5)	22.5‡ (n = 8)
Total airborne on the cascade impactor†	13.5 (0.99)§ (n = 4)	8.8 (0.4)§ (n = 8)
Associated with particles ⩽ 2/5 μm‖	2.9 (27 ± 5%)	4.1¶ (38 ± 14%)
2.4		
Total airborne on the parallel filter†	18.05** (n = 4)	26.4 (n = 6)
Total airborne on the cascade impactor†	17.2 (0.91)§ (n = 4)	17.1 (0.75)§ (n = 4)
Associated with particles ⩽ 2.5 μm‖	2.5 (14 ± 8%)	3.2 (21 ± 11%)

Definition of abbreviations: ACH = air exchange per hour.
* The 0.2 ACH obtained by closing the central heating duct and the window. The 2.4 ACH obtained by opening the window (1.10 × 0.73 m) and using a 20-inch domestic fan (airflow = 7.8 m³/min).
† Mean values of total airborne *Fel d* I (ng/m³) during 50-min sampling.
‡ Under low air exchange (0.2 ACH) airborne *Fel d* I increased significantly ($p < 0.05$; Student's *t* test) with the presence of furnishings.
§ Mean ratio of total airborne *Fel d* I collected on the cascade impactor to total airborne *Fel d* I measured on the parallel filter.
¶ The percentage of allergen carried on small particles measured on the cascade impactor was significantly higher (Wilcoxon rank sum test, $p < 0.05$) in the furnished room at low ventilation rate than in the unfurnished room at 0.2 and 2.4 ACH.
‖ Mean quantity of *Fel d* I particles associated with less than 2.5 μm. Values in parentheses indicate the mean percentage ± SD of total collected on cascade impactor.
** Increasing air-exchange rate in the unfurnished room increased airborne *Fel d* I significantly ($p < 0.05$, Student's *t* test).

Effect of Air Exchange and the Presence of a Carpet on Airborne Cat Allergen

The cat was left in the room for 20 h/day, and airborne allergen was sampled 1 h after removal of the cat. Preliminary experiments (data not shown) established that levels of airborne *Fel d* I reached a steady state within 1 h after the cat left the room. Under unfurnished conditions airborne *Fel d* I was increased when the air-exchange rate was increased (from 0.2 to 2.4 ACH). The percentage of small particles was higher with a low ventilation rate (table 2). In other houses this effect was more marked (table 3): in a house with 0.3 ACH 30% of the airborne *Fel d* I was associated with particles ⩽ 2.5 μm; the comparable figure in a house with 1.6 ACH was 14%. However, in the experimental room the presence of furniture appeared to influence the assessment of particle size. In the presence of the carpet the total *Fel d* I measured on the stages of the cascade impactor was ~45% of the amount recovered on the parallel filter; the comparable figure in the same room unfurnished was ~90% (table 2). These results suggest that the carpet not only acts as a reservoir of dust containing *Fel d* I but also appears to influence the properties of airborne particles carrying the allergen.

Comparison of Falling Properties of Particles Carrying Fel d *I at Different Air-exchange Rates*

High levels of airborne *Fel d* I were generated using a vacuum cleaner without a filter (SHOP VAC,® Model 600C; Shop Vac Corp., Williamsport, PA) in the 33-m³ room under furnished conditions. Air was sampled for 30 min during disturbance and at 20 and 60 min after disturbance (figure 2). After 20 min with 0.2 ACH cat allergen remained airborne predominantly on small particles (< 2.5 μm) and less than 3% of the large particles were still airborne. In contrast, with an air-exchange rate of 2.4 ACH, 20 min after disturbance only 5% of small particles and 24% of large particles remained airborne. The results showed that increasing ventilation in a carpeted room had little effect on total levels of cat allergen remaining airborne but changed the particle size distribution.

Effect of Using a HEPA Filter Air Cleaner and HEPA Vacuum Cleaner on Airborne Cat Allergen

Preliminary experiments in the unfurnished room with 0.2 ACH demonstrat-

TABLE 3

PARTICLE SIZE DISTRIBUTION CARRYING *Fel d* I: COMPARISON BETWEEN THE EXPERIMENTAL ROOM AND TWO HOUSES

	Experimental Room*							
	0.2 ACH, n = 8		2.4 ACH, n = 8		1.6 ACH, n = 3		0.3 ACH,‡ n = 3	
Stage	(ng/m³)	(%)§	(ng/m³)	(%)§	(ng/m³)	(%)§	(ng/m³)	(%)§
I	3.2	25	6.6	45	0.74	30	5.4	15
II	1.0	30	3.6	27	0.33	22	15	45
III	0.6	7	0.5	6.2	0.7	24	6	15
IV + final filter	4.3	38	0.4	21	0.2	14	8	25
	9.4		11.1		2.5		35.4	
	27.6		16		7.7		41	

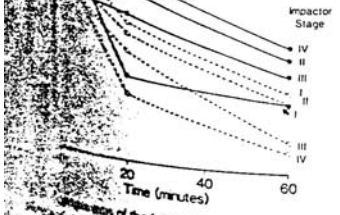
...m room with a carpet and an armchair.
...ed living room with three windows with a wooden floor covered by a rug in a 10-yr-old house (1.5 ACH).
...m located in a basement with no window, a carpeted floor, and a sofa in a 10-yr-old house (0.3 ACH).
...ge values.

...h of air filtration with an air ...at high or low flow rate decreased ...rne *Fel d* I only modestly, that is, ...and 33%, respectively. If the plas... was also vacuum cleaned for 15 ..., however, then the room air cleaner ...ed the airborne allergen by 98% ... 4). Similar results were obtained ...ther a low or high flow rate on ...room air cleaner. In contrast, experi... using the air filter in the furnished ... and with a low air-exchange rate ...3 ACH) produced only a 70% fall in ...orne allergen (table 4). In keeping ... our previous results, running the ... air cleaner in the presence of the cat ... very effective at reducing the lev... of airborne allergen, causing a reduc... from 75 to 24 ng/m³ *Fel d* I.

Discussion

...ses to allergens derived from cats ...important cause of allergic disease, ...especially asthma (3). Despite the obvious nature of the source, patients are often unwilling to recognize the causal nature of the relationship or alternatively are unwilling to remove the cat. For these reasons it is important to understand the factors that influence airborne cat allergen and to develop techniques for reducing exposure. Using an experimental room we have analyzed the separate contributions of the cat itself and the other elements of the room, including furniture, ventilation, and disturbances like vacuuming. Previous studies on domestic houses showed that cat allergen could become airborne on particles less than 2.5 μm in diameter. Indeed, in some houses the levels of allergen associated with small particles were comparable to the quantities found necessary by other investigators to produce acute airways obstruction (9). This is in contrast to previous results with dust mite or pollen allergens in which the allergen is predominantly carried on large particles (10), and it has not been shown that levels of allergen comparable to those used for bronchial provocation become airborne on *small* particles (10, 18). From published studies (8, 11) it is possible to estimate that bronchial provocation of patients with asthma who are allergic to cats requires between 8 and 80 ng *Fel d* I inhaled over 2 min. Using the figure of 8 ng as a bronchial provocation "dose" it is then possible to evaluate levels of and changes in airborne cat allergen according to the time it would take a patient to inhale a provocation dose.

The present results demonstrate a sharp increase in airborne cat allergen within minutes of a cat entering a room. In a 33-m³ room this increase varied (with one cat) from 30 to 90 ng/m³. This represents a level of small particles sufficient to cause a bronchial response within 26 min. Similar increases have been reported previously (6, 8). Those authors also reported variability between cats and, taking the values of Swanson and colleagues, our cat appeared to be an average producer of allergen (12). It has been known for many years that washings from a cat contain high levels of cat allergen, predominantly *Fel d* I (5). Very recently Glinert and colleagues reported that repeated washing of a cat at monthly intervals over 7 months produced a consistent decrease in the quantity of cat allergen recovered (4). Our results confirm these findings and demonstrate that this reduction is paralleled by a marked (90%) decrease in the quantity of allergen becoming airborne off the cat. This fall in the quantity of allergen becoming airborne and in the quantity that can be washed off the cat appears to suggest that there is a progressive reduction in the rate of production of allergen by the cat. Certainly the quantities recovered weekly from the cat are far



...ation of the falling properties of particles ... collected on each stage of the cascade ... furnished room at 0.2 ACH (closed ... 2.4 ACH (open circles). Airborne mea... ...ance (time zero) and starting 20 and 60 ... and of the disturbance.

TABLE 4

EFFECT OF CLEANING MEASURES ON TOTAL AIRBORNE CAT ALLERGEN (ng/m³) BEFORE AND AFTER USING A HEPA FILTER AIR CLEANER AND A HEPA FILTER VACUUM CLEANER

Cleaning	Baseline*	After 3-H Air Filtration†	After Using Vacuum Cleaner and Air Cleaner‡
Uncarpeted room§	12.8	5.8 (56%)‖	< 0.2 (98%)‖
	n = 3	n = 3	n = 3
Carpeted room	11.7	10.9 (7%)‖	3.5 (70%)‖
	n = 2	n = 2	n = 2

* A 30-min air sampling.
† Air sampling for 30 min ... air cleaner at 400 or 200 m³/h. Values in parentheses indicate the mean percentage reduction ... with baseline values.
‡ Vacuuming for 15 min ... by 30 min of air filtration at 400 or 200 m³/m.
§ A 33-... room with 0.3 ACH.
‖ Percentage of decrease ... the baseline.

less than the apparent daily accumulation in the carpet. Judging from the quantities obtained in washings about 0.4% of the allergen on the cat is released per hour. It is now clear that *Fel d* I is produced both from the pelt and from cat saliva (19–24). Direct observation confirmed that our cat was licking himself *more* than usual after being washed. Thus if saliva is the major source of allergen on the fur, it is surprising that allergen did not reaccumulate more rapidly after washing. Attempts to measure the allergen produced by the cat breathing suggest that less than 10% of the airborne allergen comes directly from this source. Taken together the results suggest that the pelt is a, or the, major source of *Fel d* I and that washing the cat regularly can reduce this source markedly. Taking the small particle data in table 1, washing the cat reduced the level of small particles by 20-fold to a level that would be expected to take 8 h to produce a bronchial provocation response. It remains to be shown whether washing the cat weekly will reduce the accumulation of cat allergen in reservoirs within the house.

Using the experimental room we confirmed that low ventilation rate can increase the proportion of allergen associated with small particles. We assume that particles are released from the carpet and that with a low ventilation rate the small particles, which fall very slowly, accumulate in the air. Our estimate of the total quantity of allergen in the carpet and the ventilation rate suggests that a very small fraction (~0.001%) of the allergen on the carpet becomes airborne per hour. The importance of low ventilation rate in "allowing" the accumulation of small particles was supported by further studies on two houses with very different air-exchange rates. In a house with 0.3 ACH 25% of the airborne *Fel d* I was associated with particles $\leqslant$ 2.5 μm in diameter; the comparable figure in a house with 1.6 ACH was 14%.

Increasing ventilation rate is often regarded as beneficial for room air quality. Although increased ventilation decreased allergen associated with small particles, the total quantity particularly increased in the absence of carpeting. We assume that the relatively small quantities of cat allergen on the plastic sheet are more easily disturbed than those trapped within the carpet. Our previous results in a house suggested that a HEPA room air cleaner was effective in reducing airborne cat allergen only after aggressive cleaning of the floor (9). Furthermore, using a vacuum cleaner with an effective filter had little effect on total airborne *Fel d* I during cleaning but reduced the level of allergen on small particles. In an uncarpeted room the combination of vacuum cleaning and a room air cleaner reduced airborne cat allergen by 98%. In contrast, in the same room with a carpet the airborne *Fel d* I was reduced by only 70%. These results are best explained if the carpet acts as a reservoir to continuously replace the airborne allergen. Replacing the airborne allergen could be explained by an increase in the quantity coming off the carpet per hour from 130 to 1,600 ng, that is, from 0.001 to 0.02%/h.

TABLE 5

PROPOSED PROCEDURE FOR REDUCING AIRBORNE CAT ALLERGEN LEVELS

1.	Remove cat either completely or keep outdoors
2.	Polished flooring, no carpeting Minimize upholstered furniture Vacuum clean with high-efficiency filter Air filtration Wash cat weekly

Based on these results it is possible to propose a regimen for reducing airborne cat allergen (table 5). Removing the cat (or keeping it outside) is the most effective measure. However, even when the cat is removed the level of *Fel d* I in the dust falls slowly. It may take 16 to 24 wk for the level of allergen to fall to the levels found in houses without a cat (25). Furthermore, it is important to remember that passive transfer of cat allergen into a house without a cat can produce significant levels of allergen in the dust. Recently we have seen a house without a cat in which the floor dust contained 80 μg *Fel d* I/g, which appeared to have been transferred by daily visits to a house with a cat. In a house with a cat the two major sources of allergen are the cat itself and the furnishings. If carpeting and other soft furnishings are removed, cleaning the room and the air appears to be relatively simple. The present results suggest that regular washing of the cat can dramatically reduce the contribution of the cat to airborne allergen. Overall, the results suggest that realistic changes in a house could reduce the quantity of allergen to a level that would take more than 10 h to produce a bronchial response. Certainly these changes will allow direct clinical trials to assess the effectiveness of these procedures in reducing symptoms in cat-allergic patients.

Acknowledgment

The writers thank Nilfisk of America for providing the HEPA filter vacuum cleaner and Enviracaire Corporation for the HEPA air cleaner. We are also grateful to Sean Bobbett and Ian Webb for help in taking care of the cat and experimental room; to Madeleine Watkins for preparing the figures; and to Nancy Malone for preparing the manuscript.

References

1. Gergen PJ, Turkeltaub PC, Kovar MG. The prevalence of allergic skin test reactivity to eight common aeroallergens in the US population: results from the Second National Health and Nutrition Examination Survey. J Allergy Clin Immunol 1987; 80:669–79.
2. Ohman JL. Allergy in man caused by exposure to mammals. J Am Vet Med Assoc 1978; 172: 1403–6.
3. Pollart SM, Chapman MD, Fiocco GP, Rose G, Platts-Mills TAE. Epidemiology of acute asthma: IgE antibodies to common inhalant allergens as a risk factor for emergency room visits. J Allergy Clin Immunol 1989; 83:875–82.
4. Glinert R, Wilson P, Wedner HJ. *Fel d* I is markedly reduced following sequential washing of cats (abstract). J Allergy Clin Immunol 1990; 85:327.
5. Ohman JL, Baer H, Anderson MC, Leitermann K, Brown P. Surface washes of living cats: an improved method of obtaining clinically relevant allergen. J Allergy Clin Immunol 1983; 72:288–93.
6. Findlay SR, Stotsky E, Leiterman K, Hemady Z, Ohman JL. Allergens detected in association with airborne particles capable of penetrating into the peripheral lung. Am Rev Respir Dis 1983; 128:1008–12.
7. Swanson MC, Agarwal MK, Reed CR. An immunochemical approach to indoor aeroallergen quantitation with a new volumetric air sampler: studies with mite, roach, cat, mouse, and guinea pig antigens. J Allergy Clin Immunol 1987; 76: 724–9.
8. Van Metre TE, Marsh DG, Adkinson NF, *et al.* Dose of cat (*Felis domesticus*) allergen 1 (*Fel d* I) that induces asthma. J Allergy Clin Immunol 1986; 78:62–75.
9. Luczynska CM, Li Y, Chapman MD, Platts-Mills TAE. Airborne concentrations and particle size distribution of allergen derived from domestic cats (*Felis domesticus*). Am Rev Respir Dis 1990; 141:361–7.
10. Tovey ER, Chapman MD, Wells CW, Platts-Mills TAE. The distribution of dust mite allergen in the houses of patients with asthma. Am Rev Respir Dis 1981; 124:630–5.
11. Ohman JL, Findlay SR, Leitermann SB. Immunotherapy in cat-induced double blind trial with examination of *in vivo* and *in vitro* responses. J Allergy Clin Immunol 1984; 74:230–9.
12. Wentz PE, Swanson MC, Reed CE. Variability of cat allergen shedding. J Allergy Clin Immunol 1990; 85:94–8.
13. May KR. The cascade impactor: an instrument for sampling coarse aerosols. J Sci Instrum 1945; 22:187–95.
14. Platts-Mills TAE, Heymann PW, Longbottom

JL, Wilkins SR. Airborne allergens associated with asthma: particle size carrying dust mite and rat allergens measured with a cascade impactor. J Allergy Clin Immunol 1986; 77:850–7.
15. Luczynska CM, Arruda LK, Platts-Mills TAE, Miller JD, Lopez M, Chapman MD. A two site monoclonal antibody ELISA for the quantification of the major Dermatophagoides spp allergens *Der p* I and *Der f* I. J Immunol Methods 1989; 118:227–35.
16. Chapman MD, Aalberse RC, Brown MJ, Platts-Mills TAE. Monoclonal antibodies to the major feline allergen *Fel d* I. II. Single step affinity purification of *Fel d* I, N-terminal sequence analysis, and development of a sensitive two-site immunoassay to assess *Fel d* I exposure. J Immunol 1988; 140:812–8.
17. De Groot H, van Swieten P, van Leeuwan J, Lind P, Aalberse RC. Monoclonal antibodies to the major feline allergen *Fel d* I. Biologic activity of affinity-purified *Fel d* I and of *Fel d* I-depleted extracts. J Allergy Clin Immunol 1988; 82:778–86.
18. Platts-Mills TAE, Heymann PW, Longbottom JL, Wilkins SR. Airborne allergens associated with asthma: particle sizes measured with a cascade impactor. J Allergy Clin Immunol 1986; 77:850–7.
19. Ohman JL, Lowell FC, Bloch KJ. Allergens of mammalian origin. III. Properties of a major feline allergen. J Immunol 1974; 113:1668–77.
20. Leiterman K, Ohman JL. Cat allergen 1: biochemical, antigenic and allergic properties. J Allergy Clin Immunol 1984; 74:147–53.
21. Lowenstein H, Lind P, Weeke B. Identification and clinical significance of allergenic molecules of cat origin. Allergy 1985; 40:430–41.
22. Anderson M, Baer H. Allergenically active components of cat allergen extracts. J Immunol 1981; 127:972–5.
23. Bartholome K, Kissler W, Baer H, Kopietz-Schulte E, Wahn U. Where does cat allergen 1 come from? J Allergy Clin Immunol 1985; 76:503–6.
24. Dabrowski AJ, van der Brempt X, Lucciani P, Charpin D, Vervloet D. Is cat saliva the unique source of *Fel d* I allergen (abstract). J Allergy Clin Immunol 1990; 85:328.
25. Wood RA, Chapman MD, Adkinson NF, Eggleston PA. The effect of cat removal on *Fel d* I content in household dust samples. J Allergy Clin Immunol 1989; 83:730–4.