The effect of vacuum cleaners on the concentration and particle size distribution of airborne cat allergen

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Background: *Vacuum cleaners are essential for the removal of dust from the surface of carpets; however, they may also contribute to airborne dust both by leakage through the cleaner and disturbance of floor dust.*
Methods: *The present studies used established techniques for measuring airborne* Fel d *I to study the effects of vacuum cleaners on airborne cat allergen under laboratory conditions and in houses with cats. Nine different models were loaded with dust containing 50 mg* Fel d *I and run for 15 minutes in a laboratory room (volume~18 m^3). Leakage was expressed as the airborne concentration of allergen in nanograms per cubic meter.*
Results: *Cleaners incorporating a double-thickness dust bag either did not leak, that is, less than 0.4 ng* Fel d *I/m^3 or had minor leakage~5 ng/m^3. Vacuum cleaners with single-thickness paper bags leaked more, that is, 15 to > 90 ng/m^3 with the exception of the cleaner with an efficient outer bag. Detailed studies on a vacuum cleaner that leaked showed that placing dust in the bag, replacing the dust bag with a double-thickness bag, and placing an electrostatic filter over the exhaust reduced levels from greater than 90 ng/m^3 to less than 2 ng/m^3. Two water-filter vacuum cleaners each emitted cat allergen (up to > 100 ng/m^3) with a mean of~90% on particles less than 2.5 μm diameter. This emission could be almost completely controlled by taping electrostatic filter paper over the air outlet.*
Conclusions: *In houses with cats, different models of vacuum cleaners could either reduce or increase total airborne allergen, and could also selectively increase certain particle sizes. These results suggest that cat allergen is a good model for studying the effectiveness of vacuum cleaners recommended to allergic patients. (J ALLERGY CLIN IMMUNOL 1993;91:829-37.)*

Key words: *Vacuum cleaners, airborne cat allergen, double-thickness dust bag, electrostatic filter*

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Abbreviations used
BSA: Bovine serum albumin
ELISA: Enzyme-linked immunosorbent assay
HEPA: High-efficiency particulate air (filter)
mAb: Monoclonal antibody
PBS: Phosphate-buffered saline

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Surveys carried out in the United States have shown that at least 2% of the population are allergic to proteins derived from the domestic cat *(Felis domesticus)*, and that approximately one third of these individuals live in a house with a cat.[1-3] Characteristically individuals allergic to cat report rapid onset of symptoms of rhinitis, conjunctivitis, or asthma on exposure to a cat or on entering a house with a cat. However, among individuals who live in a house with a cat the temporal relationship between exposure and symptoms may be less obvious. It has also been reported that IgE antibodies to cat allergen are significantly associated with emergency room visits for asthma.[4] Until recently it was thought that the major cat allergen (*Fel d* I) was a glycoprotein of salivary origin.[5-7] However, current data suggest that the antigen is produced by sebaceous glands and to a lesser extent by basal epithelial cells, and that it is present in high concentration on the surface of the epidermis and fur.[8,9]

We and others have reported that cat allergen is present airborne in all houses with a cat even in undisturbed conditions. Furthermore, in most houses a significant proportion of airborne cat allergen can be detected in association with small particles.[10-13] This is in contrast to the major dust mite allergen *Der p* I, which cannot be detected airborne in undisturbed conditions, falls rapidly after disturbance, and exists exclusively, or at least predominantly, on particles larger than 10 μm diameter.[12,14-17] The concentration of cat allergen in house dust can be very high (up to 3 mg/gm) although it is unusual to find levels of mite allergen greater than 200 μg/gm of dust. It is probable that the quantity of airborne cat allergen depends on both the cat itself and on the presence of allergen in upholstered furnishings, carpets, and draperies, which act as a reservoir.[11,18,19] Furthermore, recent studies show that cat allergen is widely distributed on wall surfaces.[20] These factors explain why cat allergen may persist in a house for up to 6 months after removal of the cat.[21] However, reductions in airborne cat allergen, even in the presence of the cat, can be achieved by reducing furnishings, washing the cat, vacuum cleaning, and air filtration.[19]

Earlier studies have shown that disturbance caused by a fan or room air cleaner and decreased air exchange rates could increase airborne cat allergen levels.[11] Preliminary studies also indicated that vacuum cleaners could influence both the quantity and particle size distribution of airborne *Fel d* I. We report here the effect of several types of vacuum cleaners on airborne cat allergen both under laboratory conditions and in houses with cats. The results demonstrate that some vacuum cleaners leak particles of a variety of sizes or actually generate small droplets associated with allergen. In addition, the findings suggest that leakage through the cleaner is a major component of the increase in allergen during cleaning, and that in some cases the cleaners can be simply modified to reduce the allergen leakage.

MATERIAL AND METHODS

Air sampling

Air sampling was carried out with use of methods previously described.[11,15,16,22] In brief, a cascade impactor (Casella Mark II, Casella Lovidon Ltd., Bedford, U.K.) was loaded with four glass disks coated with 1 mm of 5% agarose-sorbitol gel (5 gm agarose [MCB AXO517-3], 50 gm D-sorbitol [Sigma Chemical Co., St. Louis, Mo. 51876] in 100 ml borate-buffered saline) and a glass fiber final filter type AP20 (Millipore, Bedford, Mass.). Total airborne particles were collected by a glass fiber filter run in parallel with the impactor.

Air was sampled at flow rates of 1.1 m^3/hour (18 L/min) monitored by a flowmeter (Wright Respirometer, Ferraris Development and Engineering Co. Ltd., Edmonton, London, U.K.). On completion of sampling, the agarose-sorbitol gels and glass fiber filters were eluted in 0.5 ml and 1.0 ml, respectively, of 1% bovine serum albumin phosphate-buffered saline (BSA PBS)-Tween 20 overnight at 4° C. Results for all experiments combined values obtained for the fourth stage of the impactor with those of the final filter and expressed them as particles equal to or smaller than 2.5 μm.[11]

Two-site monoclonal antibody (mAb) enzyme-linked immunosorbent assay (ELISA) for the quantification of *Fel d* I

Cat allergen content of the gels and glass fiber filters was assayed by a two-site ELISA with (mAbs) specific for two nonoverlapping epitopes on *Fel d* I (Fd1A and Fd1B).[23-25] Immulon-2 flat-bottom ELISA plates (Dynatech, Chantilly, Va.) were coated with 10 μg/well 6F9 anti-Fd1B mAbs in 0.05 mol/L carbonate-bicarbonate buffer (pH 9.6) and incubated overnight at 4° C. Plates were washed twice with PBS-Tween and blocked for 1 hour with 1% BSA PBS-Tween 20. After a further two washes, 100 μl aliquots of cat allergen standard (OBRR, FDA-Cat E3, 10.5 U/ml) were diluted in the range of 84 ng/ml to 0.04 ng/ml (1 mU = 4 ng) to establish a control curve. Eluates from the cascade impactor and parallel filter were added to the wells in 100 μl aliquots. The plate was incubated for 1 hour at room temperature. Plates were then washed five times and incubated for 1 hour at room temperature with 100 μl/well of biotinylated 3E4 anti-Fd1A mAbs. Streptavidin peroxidase (0.25 μg/ml) (Sigma) was added to the plate at 100 μl/well after a further five washes, and the plate was incubated at room temperature for 30 minutes. Plates were washed a final five times and developed with 100 μl 0.01 mol/L 2,2′-azino-*bis* (3-ethylbenzthiazoline-6-sulfonic acid) (Sigma A1888) in 0.07 mol/L citrate phosphate buffer pH 4.2 containing 0.03% H_2O_2 added immediately before

TABLE I. Comparison of leakage of *Fel d* I (ng/m³) from two canister vacuum cleaners with different additional filtration systems in a laboratory room*

	Background	Baseline†		Modification to filtration system					
				ES only		Foam only		No filter	
		i	ii	i	ii	i	ii	i	ii
Type *A* canister vacuum:‡									
Dust collected	<0.2	<0.2	<0.2	0.3	0.3	0.4	0.9	0.9	0.7
	(nd)	(nd)	—	(nd)	—	(nd)	—	(nd)	—
Type *B* canister vacuum:§									
Dust collected	<0.2	73.1	154.7	93.2	147.0	NA		51.2	112.0
	(nd)	(9.3%)	—	(11.6%)	—			(8.4%)	—
Dust placed	<0.2	21.9	22.5	10.8	14.7	NA		17.6	28.0
	(nd)	(2.3%)	—	(10.2%)	—			(23.0%)	—

nd, None detected; *NA*, not applicable.

*Vacuum cleaner used to pick up 15 gm house dust containing 50 mg *Fel d* 1 (collected) or 15 gm dust placed inside dust bag. In each case, the vacuum cleaner was run inside a laboratory room for the first 15 minutes of a 30-minute sampling period. Values are the mean of airborne cat allergen (i) on the cascade impactor stages, and (ii) on a parallel filter. Values in parentheses indicate the percentage of airborne cat allergen on particle sizes ≤2.5 μm diameter.

†Vacuum cleaner run with the original filtration system incorporated by the manufacturer.

‡ES = Miele Super Air Clean electrostatic filter.

§ES = Vacu-filt electrostatic filter.

use. Plates were read at 405 nm with use of a Titertek Plus Mark II plate reader (Flow Labs, MacLean, Va). Values for samples were interpolated from the linear part of the control curve and expressed as ng *Fel d* I/m³ air sampled, correcting for the volume of air sampled and the total sampling time. The detection limit for a 30-minute sampling period was 0.2 ng/m³.

Vacuum cleaners

Four major groups of vacuum cleaners were tested. The first group was the canister vacuums comprising the Miele Model S274i (denoted type *A* in the text) (Miele Appliances Inc., Somerset, N.J.), the Kenmore 4.3 (type *B*) (Sears, Roebuck & Co., Chicago, Ill), and the Electrolux L.E. (type *C*) (Electrolux, Marietta, Ga.). All canister cleaners contained an enclosed dust bag. Water-filter vacuum cleaners included the Rainbow Model D3C (type *D*) (Rexaire Inc., Cadillac, Mich.) and the Thermax Extractionaire (type *E*) (Thermax Floor Care Products, Division of Parise and Sons Inc., Reno, Nev.). Two different type *E* vacuum cleaners were tested, an older model that incorporated a transparent reservoir tank made from poly 1,4 cyclohexylene dimethylene terephthalate glycol (PCTG) plastic and a newer model that incorporated an opaque acrylonitrile butadiene styrene (ABS) plastic reservoir tank. The water-filter vacuum cleaners contained water reservoirs to trap dust in place of a dust bag. Also included in our studies was the high-efficiency particulate air (HEPA) filter vacuum cleaner (type *F*) (Nilfisk GS90, Nilfisk of America Inc., Malvern, Pa.). This was a variation of the canister variety but with a HEPA filter located at the exhaust. The final group of vacuum cleaners tested was the conventional upright comprising the Kirby Legend II Model 2HD (type *G*) (The Kirby Co., Cleveland, Ohio), the Hoover Concept One Model U3101 (type *H*) (Hoover Co., N. Canton, Ohio), and the Eureka Model 1903 (type *J*) (The Eureka Co., Bloomington, Ill.). All upright cleaners had an external dust bag contained within an outer fabric bag.

All vacuum cleaners tested were new except for types *D* and *H*, which were 2 years old. Vacuum cleaners containing single-thickness dust bags included types *B*, *G*, *H*, and *J*. Those with double-thickness bags were types *A* and *C*. The double-thickness bag used to modify other vacuum cleaners in our study was from the type A vacuum cleaner.

Vacuum cleaners are designed so that air flows through the receptacle and hose into the dust bag or water reservoir and then through any additional filters before leaving the machine at the exhaust. Different vacuum cleaners incorporated different types of exhaust filters. Vacuum cleaners types *A*, *B*, and *E* contained foam exhaust filters. In addition, type *A* contained a secondary electrostatic filter similar to that in the type *C* machine. None of the uprights contained an exhaust filter. Vacuum cleaners were modified during our research by means of Vacu-filt electrostatic filter (Allergy Control Products, Ridgefield, Conn.) unless specified otherwise. A HEPA-filter room air cleaner was used to clear airborne allergen from the laboratory room between runs (Enviracaire, Model EV-1, Enviracaire Corp., Hagerstown, Md.).

Design of experiments

Laboratory room. Vacuum cleaners were tested in an 18 m³ (approximately 10 × 7 × 10 feet) airtight laboratory room with no windows, a single door, and a vinyl floor. Air vents were blocked to eliminate air exchange. Airborne cat allergen was sampled with a cascade impactor and a

TABLE II. Total airborne *Fel d* I (ng/m³) leaked from different vacuum cleaners run in an airtight laboratory room*

	Canister			Water-filter	
	Type *A*†	Type *B*	Type *C*	Type *D*†	Type *E*†
Total *Fel d* I in ng/m³					
Cascade impactor (i)	<0.2	73.1	4.4	86.0	25.0
Parallel filter (ii)	<0.2	154.7	8.0	144.7	26.4
% on particles <2.5 μm	nd	9.3	11.4	97.0	82.0
Total *Fel d* I in ng/m³ with ES filter:					
Cascade impactor (i)	<0.2	93.2	—	5.1	2.6
Parallel filter (ii)	<0.2	147.0	—	4.4	2.1
% on particles <2.5 μm	nd	11.6	—	63.0	65.0
Flow rates (cfm)§	86	85	78	55	54
Suction pressure (inches H_2O)	75	66	70	60	69

nd, None detected.

*Vacuum cleaners filled with 15 gm house dust containing 40 to 50 mg *Fel d* I and run inside laboratory room for 15 minutes. Air sampled for 30 minutes (15 minutes during running of machine and 15 minutes after).

†Marketing strategies for these cleaners recommend them for use by allergic patients.

‡No suitable attachment was available to measure flow rate and suction pressure on upright type *H* vacuum cleaner.

§Measured by anemometer.

parallel filter placed inside the laboratory room at a height of 24 inches from the floor. The cascade impactor and parallel filter were connected to a vacuum pump that remained outside the room. Background air sampling was carried out for 30 minutes both without the vacuum cleaner present and also during operation of the cleaner but with no dust in the bag or water reservoir. These background values were equal to or less than 0.2 ng/m³ airborne *Fel d* I in each case. Vacuum cleaners were initially placed outside the room, switched on for 10 seconds or less and used to collect sieved dust containing 40 to 50 mg *Fel d* I. The vacuum cleaner was then switched off and placed inside the room at a distance of 6 feet from the cascade impactor and parallel filter. The vacuum cleaner was switched on again for 15 minutes. Air was sampled for a total of 30 minutes, 15 minutes during operation of the machine and 15 minutes after. On completion of studies on individual vacuum cleaners the laboratory room floor was vacuumed. In addition, the walls and floor were washed thoroughly with warm water to remove any allergen present on surfaces, and the room was also ventilated.

The dust sample used in the present studies was obtained from a house with two indoor cats by collection in a vacuum cleaner bag. Sieved dust from this bag contained a high concentration of *Fel d* I, ~3 mg/gm dust. The dust was freshly sieved through a mesh size of 0.03 cm, and 15 to 20 gm of fine dust was used as the source of cat allergen in each experiment.

Houses with cats. Houses with cats were sampled with use of the cascade impactor and parallel filter. Rooms were selected in which the cats spent the most time but were studied when the cat had been absent for at least 1 hour. An area of rug or carpet in each house was vacuumed for 15 minutes with a new dust bag in the cleaner or, in the case of the water-filter vacuum cleaner, clean tap water in the reservoir. Air was initially sampled for 30 minutes before vacuuming to obtain a baseline airborne cat allergen level. Sampling was then carried out for 15 minutes during vacuuming and 15 minutes after switching off the machine (total sampling time of 30 minutes). Dust from the vacuum cleaner bag was weighed and extracted in borate-buffered saline, pH 8, overnight at 4° C and assayed for *Fel d* I. An aliquot of the content of the water-filter vacuum cleaner reservoir was assayed directly.

RESULTS

Dust obtained from houses with cats was used to test the filtration efficiency of vacuum cleaners in a laboratory room. All results obtained were the mean of two experiments. The detailed results for two canister cleaners are shown in Table I. The type *A* cleaner showed minimal leakage of cat allergen, and the leakage was only marginally increased when the additional filters were removed (Table I). By contrast, type *B* showed extensive leakage of cat allergen associated with a range of sizes of particles even when an electrostatic filter was placed in the dust compartment covering the site of the exhaust. In this case it appeared that leakage was occurring around the site of the connection between the hose and dust bag. To test if this was the case, dust was placed in the bag rather than collected. Under these circumstances leakage was less but was still ~22 ng/m³ and even with an electrostatic filter was only reduced by 50% (Table I). Placing a

HEPA-filter	Conventional upright		
Type *F*†	Type *G*†	Type *H*‡	Type *J*
<0.4	0.3	9.5	27.6
<0.4	<0.2	8.3	35.8
nd	nd	27.4	<1.0
—	—	—	—
—	—	—	—
—	—	—	—
101	77	—	39
76	32	—	20

section of double-thickness dust bag over the exhaust on the type *B* machine caused a further reduction in leakage to 5.5 ng/m³ (data not shown). When the single-layer dust bag was replaced with a double-thickness dust bag and combined with an electrostatic filter, allergen levels were reduced to less than 2 ng/m³ (data not shown). These results strongly suggest that the vacuum cleaner dust bag is the critical factor in limiting emissions and that the additional filters have little role. The dust bag for canister type *A* was double-thickness, and examination of a full bag revealed fine particulate material between the inner and outer layers. When the type *A* cleaner was operated with a dust bag that had been used repeatedly and contained more than 200 mg *Fel d* I, the resultant airborne allergen level in the room was still only 2.1 ng/m³. A series of nine vacuum cleaners were tested under similar conditions (Table II). The water-filter cleaners, type *D* and type *E* (both older and newer models) generated airborne *Fel d* I predominantly associated with fine particles. However, this release of particles was in large part controlled by applying electrostatic filter material to the exhaust route. The electrostatic filter was taped around the motor housing unit of the type *D* vacuum cleaner and placed under the reservoir tank in the type *E* machine. Data obtained from studies carried out on a newer type *D* vacuum cleaner correlated well with those described in this study. The canister cleaners varied widely in their leakage. This variation seemed to be primarily a function of the quality of the paper dust bag. Electrostatic filters alone had very little effect in controlling leakage from the canister cleaners (Table I). The upright cleaners showed variable leakage. The model that leaked only minimally (type *G*) had a high-quality outer bag, which clearly played a major role, because running the cleaner with its inner bag exposed gave rise to airborne *Fel d* I levels of 17 ng/m³.

Testing three models that leaked showed that for two of the vacuum cleaner models with paper dust bags the emission of allergen decreased markedly with time; however, the type *D* water-filter cleaner released small particles consistently once there was cat allergen in the reservoir (Table III). This was also the case for the other water-filter vacuum cleaner (data not shown). More extensive studies carried out on the newer type *E* water-filter vacuum cleaner showed that this did not leak at a consistent rate. Leakage varied on consecutive runs from 3.7 ng/m³ to greater than 40 ng/m³ *Fel d* I (data not shown). High levels corresponded with the presence of water underneath the reservoir tank at the site of the exhaust. This suggests that spillage of water from the reservoir tank down the exhaust tube can occur occasionally, leading to leakage of cat allergen. This leakage could not be restricted by the use of a secondary filtration system manufactured by the vacuum cleaner company because the filter became saturated when spillage of water occurred. For the six vacuum cleaners that showed significant leakage, the particle size distribution of allergen leaked is shown in Fig. 1. The results confirmed that the water-filter cleaners released allergen associated with small particles, whereas for all the other cleaners the particles emitted were of a range of sizes. To test the nature of the small particles emitted by the water-filter vacuum cleaners, house dust containing 40 mg *Fel d* I was extracted in 600 ml tap water, centrifuged at 15,000 rpm, and filtered through a 0.2 μm Nalgene filter (Fisher Scientific Co., Pittsburgh, Pa.). More than 99% of airborne allergen (60.5 ng/m³) detected after running the vacuum cleaner (type *D*) with the filtered extract in the reservoir was associated with particle sizes less than 2.5 μm. These results strongly support the view that the particles emitted are indeed soluble allergen dissolved in water droplets. The leakage of airborne allergen on predominantly large particles seen with the type *B* canister cleaner (Fig. 1) was surprising because particles this size are not a major part of airborne *Fel d* I in undisturbed or disturbed conditions in houses with cats.

Airborne cat allergen (*Fel d* I) before and during vacuum cleaning in houses with cats

The HEPA-filter vacuum cleaner and the water-filter cleaner type *D* were tested in three houses to assess the effects on airborne *Fel d* I (Table IV). In each house the water-filter cleaner caused an increase in airborne allergen, whereas the HEPA-filter cleaner

TABLE III. Variability of leakage of *Fel d* I over time when running different vacuum cleaners in an airtight laboratory room

Particle size (μm)	Type *B* (canister)		Type *D* (water-filter)		Type *J* (upright)	
	Fel d I (ng/m³)		*Fel d* I (ng/m³)		*Fel d* I (ng/m³)	
	Collect & run*	Run only†	Collect & run*	Run only†	Collect & run*	Run only†
2-20	62.7	6.3	1.8	0.8	27.0	1.6
1-5	3.6	0.4	0.7	0.3	0.6	0.3
<2.5	6.8	1.3	83.5	85.3	<0.2	<0.2
Total	73.1	8.0	86.0	86.4	27.6	1.9
Parallel filter	154.7	15.2	144.7	88.1	35.8	3.5

*Vacuum cleaner filled with 15 gm house dust containing~50 mg *Fel d* I and run inside airtight room for 15 minutes; air sampled for 30 minutes (15 minutes during running of machine and 15 minutes after).

†Vacuum cleaner filled with 15 gm house dust and run outside room for 15 minutes. Vacuum cleaner then brought into room and run for 15 minutes; air sampled for 30 minutes (15 minutes during running of machine and 15 minutes after).

caused a modest decrease on three occasions out of four. It is more striking that there was a sharp relative increase in the proportion of *Fel d* I associated with small particles when the water-filter cleaner was used. The mean level of small particles after running the water-filter cleaner was 63% of 22.9 ng/m³ (≈14 ng/m³) compared with 20% of 14.8 ng/m³ when using the HEPA-filter cleaner (≈3 ng/m³).

An upright cleaner (type *H*) was tested in five houses. The particle size before testing was variable with predominantly medium size particles in four houses and 55% small particles in the fifth house. For the four houses with medium size particles, there was an increase in all particle sizes during cleaning (Fig. 2a). However, there was a slight increase in the percentage of allergen carried on large particles (Fig. 2, *b*). In the house with a significant concentration of allergen on small particles there was a more marked shift to large particles (data not shown).

DISCUSSION

These experiments investigated the performance of domestic vacuum cleaners under laboratory conditions and also their effect on airborne allergen in houses with cats. Water-filter vacuum cleaners produced a significant increase in airborne *Fel d* I associated with small particles (<2.5 μm). These cleaners generated an aerosol of small particle cat allergen shown to be in the form of water droplets, the concentration of which depends on the amount of *Fel d* I in the reservoir, the length of running time, and the volume of the room. It would therefore seem reasonable to presume that this type of vacuum cleaner may also aerosolize other soluble indoor allergens. However, attempts to detect airborne dust mite allergen (*Der p* I and *Der f* I) emitted from water-filter vacuum cleaners loaded with dust have so far been unsuccessful, probably because of the lower levels of mite allergen in house dust compared with cat allergen levels.

In the present experiments both the cleaners with double-thickness bags and the HEPA-filter vacuum cleaner were very effective at retaining allergen. This was in contrast to certain models of conventional upright and canister vacuum cleaners. Particle size distribution of leaked *Fel d* I differed between the three major groups of vacuum cleaners. The canister vacuum cleaners tested caused an increase in airborne levels of cat allergen present mainly on particles in the size range of 6 to 20 μm. While running upright vacuum cleaners under laboratory conditions the greatest proportion of airborne *Fel d* I was associated with particle sizes of 2 to 15 μm. Thus leakage of *Fel d* I from dust bag vacuum cleaners (upright or canister) was linked predominantly to larger sized particles.

Our results also demonstrated that some vacuum cleaners that do leak could be modified to reduce allergen leakage. The addition of a passive electrostatic filter to the exhaust of each of the water-filter vacuum cleaners (type *D* and type *E*) effectively controlled up to more than 90% of the allergen otherwise released. Leakage from the type *B* canister vacuum cleaner could be reduced through bypassing the connection between hose and bag. It would seem that the most important factors in eliminating leakage from canister vacuum cleaners are a tight connection between hose and bag and a double-thickness dust bag.

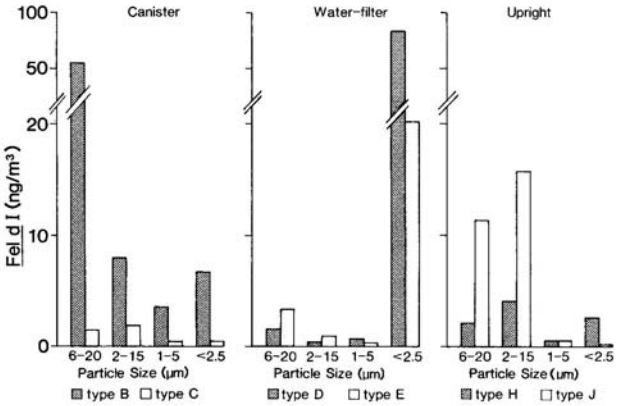

FIG. 1. Analysis of particle size of *Fel d* I leaking from vacuum cleaners when run in a laboratory room. Data are shown for six cleaners which showed significant leakage, that is more than 5 ng/m³.

TABLE IV. Airborne *Fel d* I (ng/m³) before and after vacuuming with a HEPA-filter vacuum cleaner and a water-filter vacuum cleaner in three houses*

	HEPA-filter vacuum cleaner					Water-filter vacuum cleaner				
	Fel d I airborne (ng/m³)					*Fel d* I airborne (ng/m³)				
Home	Before vac	%<2.5 μm	After vac	%<2.5 μm	mg *Fel d* It collected	Before vac	%<2.5 μm	After vac	%<2.5 μm	mg *Fel d* It collected
1	1.5	27%	1.8	39%	14.6	6.2	32%	8.7	71%	8.0
2	16.0	7%	13.6	11%	61.4	23.3	4%	40.9	78%	30.0
3A‡	39.2	46%	34.5	6%	25.6	9.2	48%	27.7	52%	11.2
3B‡	13.1	41%	9.4	24%	1.9	5.5	32%	14.2	51%	5.2
Mean	17.5	30%	14.8	20%	25.9	11.1	29%	22.9	63%	13.6

*Before, 30 minutes air sampling of undisturbed room; After, 30 minutes air sampling during and after 15 minutes vacuuming.
†Total *Fel d* I extracted from contents of vacuum cleaner bag or water reservoir.
‡3A, cats' room; 3B, living room.

An efficient filter at the outlet may play a secondary role. The continued emission of allergen from the water-filter vacuum cleaner suggests that this kind of cleaner may cause increasing amounts of allergen to be emitted as more dust accumulates in the reservoir. In contrast, use of vacuum cleaners with single-thickness dust bags may result in bursts of allergen emission because dust is collected with a significant decrease in leakage when the vacuum cleaner is running but collecting no dust. The studies in houses with cats showed that water-filter and conventional upright vacuum cleaners played a significant role in influencing the quantity and particle size distribution of airborne cat allergen. It is assumed that airborne allergen increased as a result of leakage through the cleaner, disturbance of floor dust and also the resuspension of cat allergen from other surfaces. In contrast, the HEPA-filter vacuum cleaner did not alter the airborne concentration of *Fel d* I during and immediately after vacuuming. In this relatively small number of samples no correlation was found between settled and airborne *Fel d* I as previously described by Swanson et al.[26] In conclusion, our studies suggest that different vacuum cleaners vary widely in their efficiency to retain al-

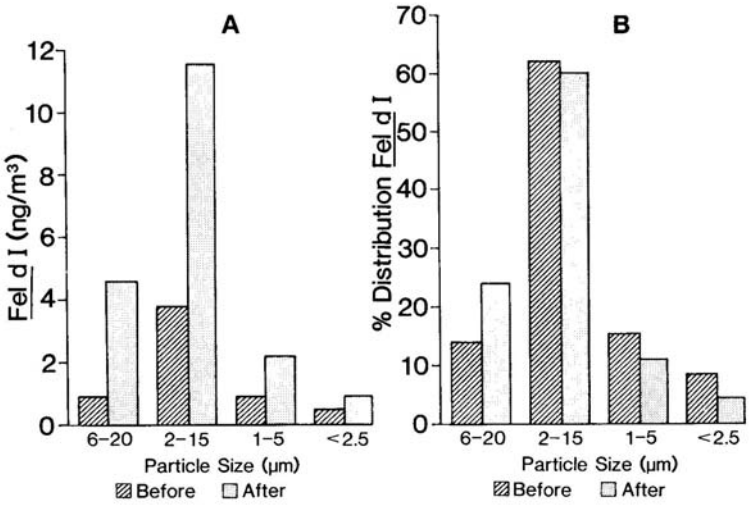

FIG. 2. Total airborne *Fel d* I (ng/m³) **(A)** and percentage of allergen on each particle size **(B)** before and after vacuuming with a conventional upright cleaner (type *H*) in four houses with cats. Samples were carried out before ▨ (30 minutes before vacuum cleaning) and after ▩ (sampling for 15 minutes during and for 15 minutes after vacuuming). Values are the mean of four houses.

lergen, and that some vacuum cleaners can be modified to reduce allergen emission. It is clearly essential that vacuum cleaners recommended for allergic patients should be tested using a relevant allergen. These tests need to address both the ability to pick up allergen and the effect on airborne allergen.[27] Our results suggest that cat allergen, because of its presence on a large range of particle sizes, is an excellent model for such testing.

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REFERENCES

1. Ohman JL. Allergy in man caused by exposure to mammals [Review]. J Am Vet Med Assoc 1978:172:1403-6.
2. Ohman JL, Findlay SR, Leitermann SB. Immunotherapy in cat-induced asthma. Double-blind trial with examination of in vivo and in vitro responses. J ALLERGY CLIN IMMUNOL 1984:74:230-9.
3. Gergen PJ, Turkeltaub PC, Kovar MG. The prevalence of allergic skin test reactivity to eight common aeroallergens in the U.S. population: results from the second National Health and Nutrition Examination Survey. J ALLERGY CLIN IMMUNOL 1987:80:669-79.
4. 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.
5. Leiterman K, Ohman JL Jr. Cat allergen 1: biochemical, antigenic, and allergenic properties. J ALLERGY CLIN IMMUNOL 1984:74:147-53.
6. Lowenstein H, Lind P, Weeke B. Identification and clinical significance of allergenic molecules of cat origin. Allergy 1985:40:430-41.
7. Anderson MC, Baer H. Allergenically active components of cat allergen extracts. J Immunol 1981:127:972-5.
8. Dabrowski AJ, van der Brempt X, Soler M, et al. Cat skin as an important source of *Fel d* I allergen. J ALLERGY CLIN IMMUNOL 1990:86:462-5.
9. Charpin C, Mata P, Charpin D, Lavaut MN, Allasia C, Vervloet D. *Fel d* I allergen distribution in cat fur and skin. J ALLERGY CLIN IMMUNOL 1991:88:77-82.
10. 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.
11. Luczynska CM, Li Y, Chapman MD, Platts-Mills TAE. Airborne concentrations and particle size distribution of allergen derived from domestic cats (*Felis domesticus*): measurements using cascade impactor, liquid impinger and a two-site monoclonal antibody assay for *Fel d* I. Am Rev Resp Dis 1990:141:361-7.
12. Swanson MC, Agarwal MK, Reed CE. 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.
13. Van Metre TE Jr, Marsh DG, Adkinson NF Jr, et al. Dose of

cat *(Felis domesticus)* allergen 1 (*Fel d* I) that induces asthma. J ALLERGY CLIN IMMUNOL 1986;78:62-75.
14. Chapman MD, Platts-Mills TAE. Purification and characterization of the major allergen from *Dermatophagoides pteronyssinus*-antigen P1. J Immunol 1980;125:587-92.
15. Platts-Mills TAE, Heymann PW, Longbottom JL, Wilkins SR. Airborne allergens associated with asthma: particle sizes carrying dust mite and cat allergens measured with a cascade impactor. J ALLERGY CLIN IMMUNOL 1986;77:850-7.
16. 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.
17. De Blay F, Heymann PW, Chapman MD, Platts-Mills TAE. Airborne dust mite allergens: comparison of group II allergens with group I mite allergen and cat allergen *Fel d* I. J ALLERGY CLIN IMMUNOL 1991;88:919-26.
18. Wentz PE, Swanson MC, Reed CE. Variability of cat allergen shedding. J ALLERGY CLIN IMMUNOL 1990;85:94-8.
19. De Blay F, Chapman MD, Platts-Mills TAE. Airborne cat allergen (*Fel d* I): Environmental control with the cat in situ. Am Rev Respir Dis 1991;143:1334-9.
20. Wood RA, Mudd KE, Eggleston PA. The distribution of cat and dust mite allergens on wall surfaces. J ALLERGY CLIN IMMUNOL 1992;89:126-30.
21. Wood RA, Chapman MD, Adkinson NF Jr, Eggleston PA. The effect of cat removal on allergen content in household dust samples. J ALLERGY CLIN IMMUNOL 1989;83:730-4.
22. May KR. The cascade impactor: an instrument for sampling coarse aerosols. J Sci Instru 1945;22:187-95.
23. Luczynska CM, Arruda LK, Platts-Mills TAE, Miller JD, Lopez M, Chapman MD. A two-site monoclonal antibody ELISA for the quantitation of the major *Dermatophagoides* spp. allergens, *Der p* I and *Der f* I. J Immunol Meth 1989;118:227-35.
24. Chapman MD, Aalberse RC, Brown MJ, Platts-Mills TAE. Monoclonal antibodies to the major feline allergen *Fel d* I. II. Single step affinity purfication 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.
25. De Groot H, van Swieten P, van Leeuwan J, Lind P, Aalberse RC. Monoclonal antibodies to the major feline allergen *Fel d* I. I. Biologic activity of affinity-purified *Fel d* I and of *Fel d* I-depleted extracts. J ALLERGY CLIN IMMUNOL 1988;82:778-86.
26. Swanson MC, Campbell AR, Klauck MJ, Reed CE. Correlations between levels of mite and cat allergens in settled and airborne dust. J ALLERGY CLIN IMMUNOL 1989;83:776-83.
27. Twiggs JT, Gray RL, DeJongh S, Marx JJ Jr. *Dermatophagoides farinae* allergen levels from two different sources within the same home: evaluation of two different collection techniques. Ann Allergy 1991;66:431-5.