

Environmental and occupational disorders

Assessment of vacuum cleaners and vacuum cleaner bags recommended for allergic subjects

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Background: High-quality vacuum cleaners and vacuum cleaner bags are often recommended to allergic patients as a means of reducing indoor allergen exposure. A number of vacuum cleaners on the market today claim to capture 99.9% of particles 0.3 μm or larger entering the vacuum cleaner, and many vacuum cleaner bags are now being sold as microfiltration bags. **Objective:** The purpose of this study was to compare the allergen-trapping abilities of vacuum cleaners and to use a new technique for testing vacuum cleaner bags that are recommended for allergic patients.

Methods: Vacuum cleaners were tested in an 18-m³ laboratory room permeated with dust containing high levels of cat allergen by using techniques previously described. Air was sampled with parallel filters in conjunction with a particle counter. The filters were assayed by ELISA for cat allergen (Fel d 1). Vacuum cleaner bags were tested by using a modified dust trap to pull sieved house dust containing a known amount of Fel d 1 across the material used for the bag. Allergen passing through the bag was trapped on a filter covering the exit of the trap and analyzed for Fel d 1.

Results: In general, vacuum cleaners designed for allergic patients leaked lower amounts of allergen (<0.5-4.04 ng/m³) than that found in our previous studies (<0.5-100 ng/m³). Single-layer vacuum cleaner bags performed poorly (1250-2640 ng recovered) compared with most of the 2- and 3-layer microfiltration bags (0.53-2450 ng recovered). The range of allergen recovered from the 2-layer bags (0.93-2450 ng recovered) highlighted the variability found between manufacturers.

Conclusion: The results suggest that although allergen leakage has been reduced, there is still room for improvement. A method of testing allergen leakage by using Fel d 1 should be applied to vacuum cleaners and bags recommended for allergic patients. (*J Allergy Clin Immunol* 1999;104:1079-83.)

Key words: Allergen avoidance, vacuum cleaners, vacuum cleaner bags

Vacuum cleaners are an essential part of home cleaning and the primary method for cleaning wall-to-wall carpeting. However, the use of vacuum cleaners can increase the quantity of airborne cat and mite allergen.¹⁻⁵ Previous evidence has suggested that adequate filtration systems could control the release of allergens, and many vacuum cleaners are now claiming to minimize allergen exposure while vacuuming.^{1,6,7} Recently, it has been suggested that vacuum cleaners could be evaluated by using airborne particle counts as an alternative to measuring specific allergen levels.⁸

We report here a continuation of earlier experiments in which vacuum cleaners were tested for their ability to limit the dispersal of cat allergen Fel d 1.¹ We also investigated the release of particles from vacuum cleaners. In addition, the allergen-trapping characteristics of different vacuum cleaner bags were evaluated by using a system developed for testing barrier fabrics.^{9,10}

METHODS

Vacuum cleaner testing

Tests were conducted inside a clean, 18-m³ laboratory room with the air vents blocked to eliminate air exchange. Airborne allergen levels were determined (as described previously)¹ by using 2 parallel filters (Millipore prefilter—2.0 μm Borosilicate microfiber glass with acrylic resin binder; Millipore Corp, Bedford, Mass) placed inside the room at a height of 24 inches from the floor and connected to a vacuum pump ($\frac{1}{4}$ horse power A-C motor, General Electric, Fort Wayne, Ind) set to 18 L/min for each of the 2 filters.¹¹ A laser particle counter (Met One Inc, Grants Pass, Ore) was run concurrently with the filters. Swabs were taken from the 4 walls before the testing began to ensure no contamination of the room. Vacuum cleaners were cleaned between testing, and new replaceable filters were used for each test. House dust obtained from vacuum cleaner bags containing a known amount of Fel d 1 was sieved through a 300- μm screen and weighed out into 36-g aliquots containing approximately 40 mg of Fel d 1.

Background values were determined by sampling the air inside the room without a vacuum cleaner present for 30 minutes and sampling the air inside the room with the vacuum cleaner turned on for 30 minutes with no dust added. The vacuum cleaner was then turned off and removed from the room. One 36-g aliquot of sieved house dust was added to the vacuum cleaner by using the flexible hose attachment (except the Oreck XL). The vacuum cleaner was placed inside the room, where it was allowed to run for 15 minutes and then turned off. Air sampling was carried out while the cleaner was running and continued for a further 15 minutes for a total sampling time of 30 minutes.

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TABLE I. Air sampling results from vacuum cleaner testing

Vacuum cleaner	No. of samples tested	Filters	Background readings*	Fel d 1 recovered without dust added to bag*	Fel d 1 recovered with dust added† to bag*
(A) Kenmore Upright	2	Prefilter leading to fan, exhaust filter	1.67 ± 1	0.76 ± 0.24	0.69 ± 0.17
(B) Miele White Pearl	2	Prefilter leading to fan, HEPA exhaust filter	0.67 ± 0.08	0.73 ± 0.14	0.67 ± 0.08
(C) Miele Air Clean Plus	2	Prefilter leading to fan, exhaust filter	<0.4	0.67 ± 0.30	0.87 ± 0.09
(D) Eureka Enviro Vac	2	Prefilter leading to fan, HEPA exhaust filter	<0.4	<0.4	0.52 ± 0.15
(E) Eureka Excalibur	2	Prefilter leading to fan, HEPA exhaust filter	1.5 ± 1.14	0.52 ± 0.07	2.06 ± 0.46
(F) Oreck-XL	2	Exhaust filter	0.66 ± 0.29	<0.4	0.42 ± 0.05
(G) Hoover Dimension Sp.	2	—	0.88 ± 0.58	<0.4	4.04 ± 1.67
(H) Kenmore 4.3 (used)‡	2	Prefilter leading to fan	1.23 ± 0.52	10.4 ± 0.27	43.1 ± 11.4
Comparison of vacuum cleaner bags§					
3M Filtrete Bag (3 layers)	1	Exhaust filter	<0.4	1.3	0.78
Hoover Micro. (2 layers)	2	Exhaust filter	0.74 ± 0.15	1.1 ± 0.21	2.61 ± 0.49
Master Design Inc.‡ (1 layer)	1	Exhaust filter	0.79	<0.52	30.9

HEPA, High-efficiency particulate air.

*Fel d 1 recovered in nanograms per cubic meters ± SEM during the 30-minute sampling period.

†Thirty-six grams of dust added containing 41 mg of Fel d 1.

‡Control.

§Hoover Runabout used as a control.

After sampling, the parallel filters were removed, folded, and placed into separate 3-mL syringes. One milliliter of 1% BSA in PBS-Tween 20 was added to each syringe, and the samples were rotated overnight at 4°C. Extracts were recovered by dispensing the contents of each syringe into separate 2.0-mL vials, which were assayed for Fel d 1 by using 2-site mAb ELISA techniques with a sensitivity equal to 0.2 ng/mL.^{11,12} Original ELISA results from the filters ranged from 0.23 ng/mL to 5.6 ng/mL. These results were multiplied by the extraction volume (1 mL), divided by 0.54 m³, and reported as nanograms per cubic meters in Table I. The correlation between the parallel filters was high ($r = 0.97$, $P < .001$). The results for individual filters were ±23% of the mean values.

Particle counts for particles ranging from 0.3 µm to greater than 5.0 µm were taken in three 10-minute cycles during the 30-minute testing time. Statistical analysis concerning the particle data was accomplished with Epistat by using ANOVA and the Newman-Keuls multiple comparisons test with a significance interval of 0.05.

Testing of vacuum cleaner bags

Vacuum cleaner bags were examined by using 2 techniques. Initially, 3 vacuum cleaner bags were tested by substituting them individually into a control vacuum cleaner (Hoover Runabout). Once again, 36 g of dust was pulled into the bag, and Fel d 1 passing through both the bag and the vacuum cleaner was measured in the air (see "Vacuum cleaner testing" section).

Vacuum cleaner bag materials were also studied by using a technique developed to test barrier fabrics. A variety of bags were obtained from retail outlets, cut into 7-in squares, and stored in protective bags. Aliquots (1.0 g) of sieved house dust containing 1.32 mg/g Fel d 1 were pulled across a variety of vacuum cleaner bags by using a modified dust trap (Fussnecker, Springfield, Ohio).⁹ Airflow through the dust trap was controlled by using a 1.1 horse power vacuum cleaner (Model #S1211, Hoover Sprint 100; The

Hoover Co, North Canton, Ohio) and monitored by using a mini-Buck calibrator (A.P. Buck, Inc, Orlando, Fla). Before testing, a laboratory control (cotton sheet) with known airflow and pressure characteristics was used to calibrate airflow through the dust trap to within 0.5 L/min of the average airflow reading. Airflow measurements through each material were taken before each test. An even spreading of dust across the materials was achieved by pulling the dust into the trap through a 14-in section of tubing. Five minutes after the dust was added, airflow readings were repeated, and the pump was shut off. A 2-µm Millipore prefilter covering the exit of the dust trap collected allergen passing through the material during each test. The filters were extracted and analyzed by using techniques described previously.⁹

Comparison studies with Der p 1 were also performed on 4 of the vacuum cleaner bags by using 1.0 g of sieved house dust containing 26.9 µg/g Der p 1. The Millipore prefilters were extracted overnight and assayed by means of ELISA.

RESULTS

Vacuum cleaners

The majority of the vacuum cleaners tested demonstrated improved allergen retaining ability compared with those studied in 1993 when Fel d 1 leakage occurred in a range of <0.5 ng/m³ to 100 ng/m³.¹ Average values of airborne Fel d 1 recovered from the parallel filters are shown in Table I. In general, the new designs featuring double thickness bags with one or more filters reduced the quantities of Fel d 1 recovered to between <0.5 ng/m³ and 4.04 ng/m³. A 5-year-old Kenmore 4.3 from our previous study and a recently purchased Hoover Runabout with a replacement bag were used as controls, leaking

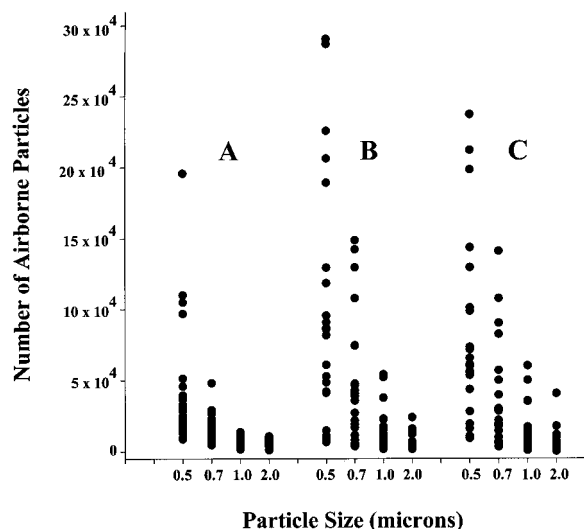


FIG 1. Graphic representation of airborne particle counts ranging from 0.5 μm to 2.0 μm for the 3 stages of vacuum cleaner testing: empty room (A), vacuum cleaner running while empty (B), and vacuum cleaner running with dust added (C). Each filled circle represents the number of particles present during a specific vacuum cleaner test. The number of particles (0.5, 0.7, and 1.0 μm) were significantly greater during both periods when the cleaners were running ($P = .05$). However, there was no significant difference between the particles that were airborne when the dust was added compared with the cleaner running without dust.

43.1 ng/m^3 and 30.9 ng/m^3 , respectively (Table I). Another previously tested vacuum cleaner (Miele Air Clean, data not shown), which did not leak allergen in 1993, was cleaned and retested for allergen leakage. Only 0.51 ng/m^3 of airborne Fel d 1 was detected in the air, clearly indicating that this cleaner had not lost its filtering efficiency.

Particle counts

The particle counts for all the vacuum cleaners tested are shown in Fig 1. A significant difference ($P < .05$) was found between the counts measured in the empty room and the counts measured while running a vacuum cleaner (either empty or containing dust) for 3 particle sizes (0.5, 0.7, and 1.0 μm). No significant difference was found between counts detected with the vacuum cleaner running and those measured with dust added to the vacuum cleaner.

We investigated the source of particles emitted from 2 types of vacuum cleaners (Figs 1 and 2). Results from Table II show particle counts measured from different types of vacuum cleaners. Although no allergen was added to either vacuum cleaner, the particle counts increased compared with background when the type B vacuum cleaner was turned on. The number of particles in the room actually decreased when the type A vacuum cleaner was turned on. Removal of the exhaust filter increases the number of particles emitted from both types of cleaners. The release of particles from vacuum cleaners has recently become an issue because some testing

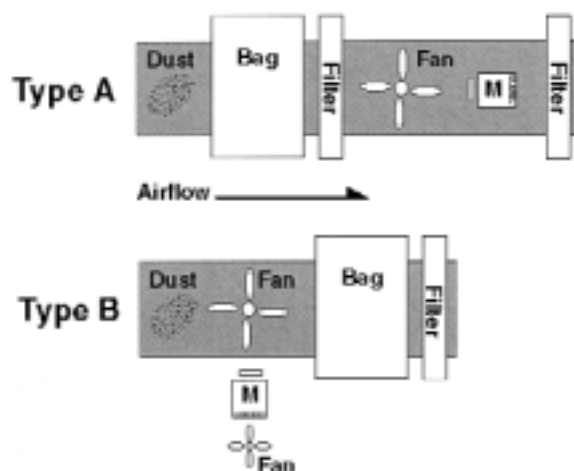


FIG 2. Two predominant designs used by vacuum cleaner manufacturers. Both designs allow airborne particles to pass through the bag and a filter leading out of the machine. In design type A, airflow passes around the motor before exiting through the exhaust filter. In type B, the motor is located outside the flow of air through the machine, and particles emitted from the motor are driven into the environment by the fan used to cool the motor. M, Motor.

TABLE II. Particle counts from 2 types of vacuum cleaners tested without dust*

Vacuum Cleaner†	Test	Change in particle counts when vacuum cleaner is running	
		Filters in place	Filters removed
Type A	1	2156	2,662,394
	2	-94,743	2,088,082
Type B	1	160,446	487,788
	2	207,627	603,898

*Values are counts above background.

†From Fig 2.

facilities are reporting particle count data as the measure of a vacuum cleaner's effectiveness. Our results illustrate the difficulty associated with this type of assessment. The vacuum cleaner designs shown in Fig 2 illustrate how particles emitted from the motor of a type B machine do not pass through a filter and can therefore add to the total number of particles detected.

Vacuum cleaner bags

Airborne testing of different vacuum cleaner bags by using the Hoover Runabout revealed that the high-quality 3-layer bag was the most effective in stopping allergen leakage (0.78 ng/m^3 Fel d 1 recovered, Table I). In contrast, the single-thickness bags allowed approximately 31 ng/m^3 Fel d 1 to pass through the machine and into the air.

Testing of the vacuum cleaner bag materials by using the modified dust trap indicated that high-quality multiple-thickness bags (referred to as "microfiltration" bags) allowed less than 25 ng of Fel d 1 to travel through the material, whereas the single-thickness bags leaked up to

TABLE III. Vacuum cleaner bags

Vacuum cleaner bag	No. of samples tested	Layers	Vacuum*	Airflow (L/min)	Fel d 1 recovered†‡
3M Filtrete	3	3	—	20.7 ± 0.01	0.53 ± 0.37
Hoover Microfiltration	2	2	G	19.5 ± 0.07	0.93 ± 0.55
Kenmore Microfiltration	2	2	A	19.6 ± 0.57	2.79 ± 2.3
Dirt Devil—Microfiltration	2	2	—	20.4 ± 0.44	13.5 ± 4.9
Kirby—Micron Magic	2	2	—	20.6 ± 0.88	20.8 ± 6.5
Sharp—Microfiltration	2	2	—	19.3 ± 0.71	24.3 ± 6.8
Sanyo	2	2	—	20.6 ± 0.25	29.1 ± 0.55
Filteraire (Eureka built-in model)	2	2	—	18.5 ± 0.77	65.2 ± 29.6
Panasonic	2	2	—	19.6 ± 0.60	90.7 ± 80.4
Castex Lite Trac	2	2	—	18.2 ± 0.83	116 ± 87
Kenmore Vacuum Cleaner Bag	3	1	H	18.1 ± 0.30	268 ± 13
Miele	4	2	B, C	20.1 ± 0.37	720 ± 18
Takamatsuya	2	2	—	21.6 ± 0.08	1030 ± 343
Electrolux Tank Multifiller	2	2	—	16.7 ± 0.73	1130 ± 153
Hoover	2	1	—	15.8 ± 0.25	1250 ± 525
Master Design Inc	2	1	—	16.9 ± 0.53	1870 ± 102
Gomikko-Q	2	2	—	21 ± 0.13	1910 ± 209
Oreck-XL	2	1	F	16.3 ± 0.19	1910 ± 373
Eureka	2	2	D, E	19.2 ± 0.39	2450 ± 235
Regina	2	1	—	19.8 ± 0.05	2510 ± 1010
American Fare	2	1	—	18 ± 0.37	2640 ± 160

*The letters indicate the use of this cleaner bag in testing of a vacuum cleaner (see Table I).

†One gram of dust added containing 1.32 mg/g Fel d 1.

‡Fel d 1 recovered in nanograms ± SEM.

2.6 µg of Fel d 1 (Table III). The 3-layer bag consistently demonstrated high airflow characteristics with low allergen leakage. Although the 2-layer bags as a group trapped significantly more allergen than the single-layer bags ($P < .005$), our results showed that 2 layers do not guarantee good performance. Each of the single-layer bags tested leaked large quantities of allergen (ie, >200 ng of Fel d 1) and would not be recommended for use by allergic individuals without a secondary filter.

As expected from our previous studies, the quantity of Der p 1 leaking through the vacuum cleaner bags was lower than the quantity of Fel d 1.⁹ The 3M Filtrete and the Sanyo materials both leaked approximately 1.1 ng of Der p 1, whereas the Miele and the Gomikko-Q leaked 26.1 ng and 28 ng, respectively.

DISCUSSION

Our results strongly suggest that allergen leakage from the vacuum cleaners has been reduced since our previous studies; however, there is still room for improvement. There are 2 basic designs used for upright and canister vacuum cleaners (Fig 2). Type A has airflow passing through the bag, through a filter, over the motor, through another filter, and out of the vacuum cleaner. In type B cleaners the motor is outside the main flow of air and requires a separate fan for cooling.

The areas generally associated with allergen release are the beater bar, the fans, the seals, and the bag-filter. The beater bar is an obvious area of agitation; however, it is unclear how much exposure is attributable to the pounding of the brushes on the carpet. Fans perform 2

functions inside the vacuum cleaner. First, they push or pull dust into the bag, and second, they provide airflow to cool the motor. The use of an air filter after the fan may be necessary if the bag leaks allergen or the motor generates significant particles. Reduction of airborne particle counts emanating from the motor (type B) can only be achieved by using an additional exhaust filter.

Many vacuum cleaners today are made of plastic shells with sealed compartments dividing the different areas. Seals are located at various points throughout the vacuum cleaner, including the inside of the tubes leading to the bag, the point at which the tubes meet the bag, the fans, the motor, and around the filters. Our reevaluation of the 5-year-old canister vacuum found only 0.51 ng/m³ airborne Fel d 1, showing that vacuum cleaners can retain efficient filtration if well designed. Long-term studies with other vacuum cleaners are needed to evaluate whether day-to-day use along with heat from the motor will affect the integrity of the seals.

Vacuum cleaner bags and filters act as trapping devices for dust and allergen passing through the system. The bag allows for the easy collection and disposal of dust, and the filters are a means of collecting the smaller particles escaping the bag. Comparing Tables I and III, it is clear that the use of filters before the fan and at the exhaust vent can effectively trap allergen, even with a leaking bag. Conversely, a vacuum cleaner without adequate secondary filters may have very little allergen leakage if the multiple-layer bag is effective (Table I).

The results presented here indicate that particles ranging from 0.5 to 1.0 µm were significantly increased while the vacuum cleaners were running. However, no signifi-

cant difference in airborne particles was found between running an empty vacuum cleaner and a vacuum cleaner with dust added. Whether the small particles released by the cleaners are fragments of the brushes or dust from the motor is not known. Our results show that the number of particles emitted from vacuum cleaners without any house dust would make it extremely difficult to evaluate allergen leakage on the basis of particle counts.

The results strongly suggest that a method of testing allergen leakage should be applied to vacuum cleaners and bags recommended for allergic patients. Our experience is that cat allergen provides an excellent model for such testing because dust from houses with a cat contains high concentrations of Fel d 1 and the smaller size of particles provides an excellent test of the filtration system.

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Correction

The following correction applies to the editorial by Tarlo and Wing (Tarlo SM, Wing EC. Diisocyanate sensitization and antibody production. 1999;103:739-41), page 739, first column, last line, which should read as follows:

Approximately 5% or fewer exposed workers become sensitized.