

High-efficiency particulate arrest-filter vacuum cleaners increase personal cat allergen exposure in homes with cats

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Background: On the basis of experimental chamber studies, vacuum cleaners with double-thickness bags and integral high-efficiency particulate arrest (HEPA) air filters are claimed to reduce airborne allergen levels and are currently recommended to allergic patients.

Objectives: The objective of this study was to investigate the effect of vacuum cleaning on personal inhaled cat allergen exposure in homes with cats.

Methods: Five unused new vacuum cleaners were compared with an old non-HEPA filter vacuum cleaner. Each vacuum cleaner was tested in an experimental chamber and in 5 homes with cats. Inhaled cat allergen was measured by nasal air sampling.

Results: New vacuum cleaners failed to leak any allergen in the experimental chamber. There was a significant increase in inhaled cat allergen during vacuum cleaning in homes ($F = 48.39$, $df = 1.4$, $P = .002$) with no difference between the old vacuum cleaner and the unused new vacuum cleaners (5-fold and 3-fold increase compared to baseline, respectively; $F = 0.005$, $df = 1.4$, $P = .95$).

Conclusions: The use of new HEPA-filter vacuum cleaners increases inhaled cat allergen in homes with cats. The use of HEPA-filter modern vacuum cleaners to reduce pet allergen exposure in the homes of pet owners should not be justified merely on the basis of experimental chamber data. (*J Allergy Clin Immunol* 2003;111:784-7.)

Key words: Nasal sampling, vacuum cleaning, *Fel d 1*, cat allergen, environmental control

Domestic vacuum cleaning may raise dust in the home and increases domestic aeroallergen exposure.¹ Formerly, vacuum cleaners could be shown to leak allergen from poorly sealed dust bag compartments, from leaky pipe joins, and from the exhaust.² However, recent improvements in design incorporating integral high-efficiency particulate air (HEPA) filters, double-thickness dust bags or bagless systems, and better compartment seals have led to an apparent improvement in the leakage of allergen.^{3,4} On this basis, both manufacturers and patient groups (eg, British Allergy Foundation, www.allergy-foundation.com) now recommend certain "high-efficiency" vacuum cleaners to allergy sufferers. Some vacuum

Abbreviations used

HEPA: High-efficiency particulate arrest

NAS: Nasal air sampler

cleaners are particularly marketed as being appropriate for pet allergens.

The recommendations for use of high-efficiency vacuum cleaners for allergy sufferers are based primarily on studies performed in an airtight experimental chamber. In such studies, vacuum cleaners are laden with standardized amounts of cat or dog allergen and switched on, and allergen exposure is assessed by using a standard air sampler. Many of the high-efficiency vacuum cleaners perform well under these conditions.^{3,4} However, experimental chamber conditions are far removed from field conditions in homes with pets. Studies of vacuum cleaning in homes with cats have utilized standard air samplers to measure airborne cat allergen levels.^{2,5} Standard air samplers and even personal lapel-mounted samplers can provide only a surrogate measure of allergen exposure. Personal directly inhaled allergen could not be measured until the very recent development of intranasal air samplers,^{6,7} and such exposure during vacuum cleaning has never been studied.

We aimed to investigate the effect of vacuum cleaning with brand-new high-efficiency and older vacuum cleaners on personal inhaled cat allergen exposure and to compare the data from an experimental chamber with real personal allergen exposure during vacuum cleaning in homes with cats.

METHODS

Vacuum cleaners

We used 5 brand-new vacuum cleaners: the upright cleaners Electrolux Ultrasmart Vac Z4870 (Electrolux AEG Floorcare, Mansfield, United Kingdom) and Hoover Pure Power Pets 1600 (Hoover Ltd, Merthyr Tydfil, United Kingdom), the cylinder cleaners Nilfisk GM410 (Nilfisk Advance A/S, Brøndby, Denmark) and Miele "The Solution 500" (Miele Company Ltd, Abingdon, United Kingdom), and the water filter cleaner Stimvak "Mitevak" (Stimvak Ltd, London, United Kingdom). During testing, each of these vacuum cleaners was compared with a 10-year-old, used vacuum cleaner with its original microfilter (Electrolux Dolphin Superboost 1200W). All new vacuum cleaners apart from the water filtration model had integral HEPA filters. Vacuum cleaner bags were used as recommended by the manufacturers (either double-thickness paper or synthetic fiber bags).

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Field study design

The study was carried out in 5 houses with cats. The same 2 investigators performed nasal air sampling in each house.^{6,8} One unused, new and the used, old vacuum cleaner were tested in a random order in the same room with a 3-day period between the tests (no vacuuming was performed during this period). Each investigator took 2 baseline 15-minute samples while mimicking vacuum cleaning with the vacuum cleaner switched off. This was followed by 2 consecutive 15-minute samples taken during the vacuum cleaning. The cat was not in the room during the testing. One baseline and one vacuuming sample from both individuals were processed by the HALOgen technique, and the other samples were processed by ELISA.

Experimental chamber testing

After completion of the field study, each of the 5 new HEPA-filter vacuum cleaners and the old non-HEPA vacuum cleaner were fitted with new collection bags and tested once in a 17-m² experimental chamber. Dust containing 36 mg of Fel d 1 was placed into the vacuum cleaner dust compartment outside the chamber. The vacuum cleaner was positioned inside the chamber, and 2 individuals simultaneously wore nasal air samplers (NAS; Inhalix, Sydney, Australia) for 15 minutes with the vacuum cleaner switched off (baseline) and then for 15 minutes with the vacuum cleaner switched on. The chamber walls, floor, and ceiling were wiped down with alcohol between each vacuum cleaner, and the air was filtered by a Honeywell air cleaner (model DA5018E; Honeywell Consumer Products, Manchester, United Kingdom) with a flow rate of 221 m³/hr for 30 minutes. Allergen exposure was measured by using the HALOgen technique alone because this method is more sensitive than ELISA for detecting inspired cat allergen-bearing particles under conditions in which allergen exposure is very low.

HALOgen assay

The pairs of adhesive tapes from NAS were laminated onto a protein-binding membrane (Inhalix) and immunostained for the cat allergen Fel d 1.⁸ Samples were coded and analyzed blind by 2 observers. Each cat allergen-bearing particle appeared as a "halo" of color surrounding an inspired particle. These particles were counted 3 times by 2 observers by using light microscopy (×40). The particle units are represented by counts in which 1 count is 1 observed cat allergen-bearing particle. The intraclass correlation coefficient for the triplicate counts was $r_1 = 0.976$. The interobserver 95% limits of agreement⁹ were -13.2 and 28.15. Statistical analysis with counts from either observer produced identical final interpretations. The counts from 1 randomly chosen observer are therefore presented.

Amplified ELISA for Fel d 1

Pairs of NAS adhesive tapes were placed in microcentrifuge tubes containing 1 mL 3% bovine serum albumin/borate buffered saline/Tween-20 0.05%. Tubes were rotated for 2 hours at room temperature. Samples were then spun and eluates recovered and stored at -20°C. Cat allergen (Fel d 1) concentration was determined by ELISA¹⁰ performed in conjunction with the Ampli-Q kit (Dako Cytomation, Ely, United Kingdom). The lower limit of detection was 0.4 ng/mL (0.1 mU/mL). All samples were measured within 1 assay. The mean coefficient of variation was 11.3%.

Statistical methods

On the basis of preliminary data, the study was designed to have at least 92% power with a 5% significance of detecting a 50% difference in allergen exposure between switching the vacuum cleaners on and off and also between the old vacuum cleaner and the group of new vacuum cleaners. Count data were square root trans-

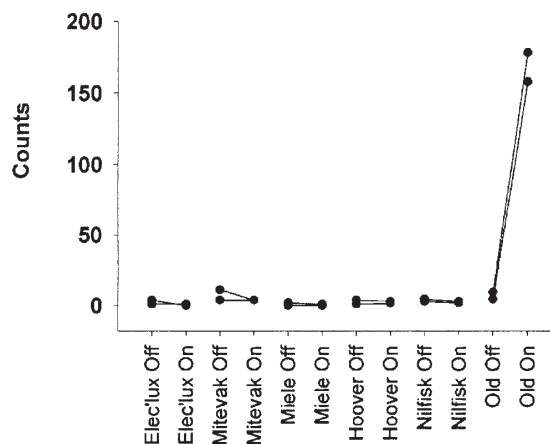


FIG 1. Experimental chamber testing of vacuum cleaners. Paired observations (baseline and switched on) are shown for each vacuum cleaner, connected by a line. There are 2 pairs of readings (1 from each observer) for each vacuum cleaner tested. The units are inspired Fel d 1-bearing particle counts (halo units).

formed, and ELISA data were log transformed for analysis.¹¹ The data were analyzed by using analysis of variance by repeated measures (SPSS 9.0; SPSS Inc, Chicago, Ill). Values that were below the detection limit for ELISA were assigned a value of half the lower limit of detection, 0.2 ng/mL.

RESULTS

Experimental chamber

We observed a marked and significant increase in inspired cat allergen in comparison with baseline when the old vacuum cleaner was switched on in the experimental room (23-fold, ratio of mean exposures; Fig 1). However, we found no increase in personal cat allergen exposure when new vacuum cleaners were switched on (median, 1.83 halos; range, 0 to 4 halos) compared to baseline levels (median, 3.5 halos; range, 0 to 11 halos). Thus, in the experimental chamber there was a marked difference between the new high-efficiency vacuum cleaners and the old, used control vacuum cleaner.

Field study: Effect of domestic vacuum cleaning on inhaled cat allergen

Inspired Fel d 1 HALO counts and inspired Fel d 1 measured by amplified ELISA at baseline conditions and during vacuum cleaning are presented in Fig 2. There was a considerable and significant increase (3- to 5-fold, ratio of medians, Table I) in personal cat allergen exposure during vacuum cleaning with both new high-efficiency vacuum cleaners and the old vacuum cleaner: with HALOgen particle counts ($F = 48.39$, $df = 1, 4$, $P = .002$) and with ELISA measurements ($F = 20.64$, $df = 1, 4$, $P = .010$).

In the field study, we found no significant difference between the unused, new vacuum cleaners and the old vacuum cleaner. The magnitude of increase in personal allergen exposure during vacuum cleaning was similar (HALOgen: $F = 0.005$, $df = 1, 4$, $P = .949$; ELISA: $F = 0.234$, $df = 1, 4$, $P = .654$). There was a good correlation

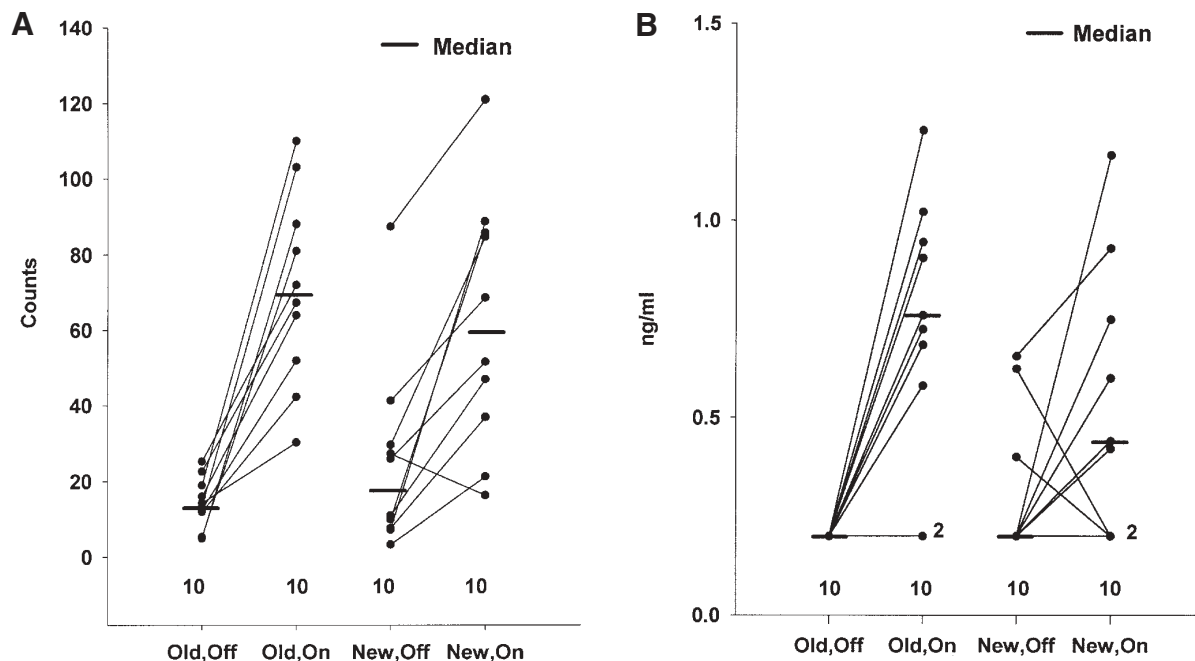


FIG 2. Field testing of vacuum cleaners. Paired observations (baseline and switched on) are shown for each test, connected by a line. There are 10 paired observations (2 observers $\times$ 5 homes) for each group of vacuum cleaners tested (old and new). The number of observations ($n = 10$) is shown for each group. Two paired observations in Fig 2, B were below the limits of detection both before and during vacuuming. (A) Inspired Fel d 1-bearing particle counts before and during vacuum cleaning. (B) Inspired Fel d 1 load (ng/mL) before and during vacuum cleaning.

TABLE I. Summary statistics for the HALOgen particle counts and ELISA measurements

	Fel d 1 particle number counts (range)		Fel d 1 load, ng/mL (range)	
	Baseline	Vacuum cleaning	Baseline	Vacuum cleaning
N	10	10	10	10
Old	14 (5-25)	70 (30-110)	0.05 (0.05-0.05)	0.19 (0.05-0.31)
New	19 (3-87)	61 (16-121)	0.05 (0.05-0.16)	0.11 (0.05-0.29)

Vacuum cleaners are grouped into either control (Old) or unused (New). Each value is the median (range) of the 10 observations in each cell (2 observers $\times$ 5 homes.)

between ELISA measurements and HALO counts for Fel d 1 ($r = 0.59$, $P < .001$).

DISCUSSION

In this real-life study, we demonstrated a 3- to 5-fold increase in personal cat allergen exposure while using both high-efficiency new vacuum cleaners and an old control vacuum cleaner. There was no difference in performance between the 2 groups, despite the fact that the new vacuum cleaners clearly perform well in the experimental chamber. How can this discrepancy be explained?

Cat allergen, by virtue of being borne on particles aerodynamically smaller than dust mite-allergen particles,¹² is more easily airborne. Consequently, it can be found in the air in homes without cats^{13,14} and in public places¹⁵ and is easily transferable on clothes.^{8,16} Homes with cats have much higher ambient airborne levels of cat allergen,^{13,14} and there are high concentrations in the

dust reservoirs of carpets, soft furnishings, and mattresses. Fel d 1 can be found adherent to wall surfaces.¹⁷ Therefore, it is likely that the observed increase in personal inhaled cat allergen that we observed during vacuum cleaning is a result of the beating bar action of the upright cleaners, the air disturbance from the exhaust flow into the room air and onto wall surfaces, and the back and forth motion of the cleaning head in all vacuum cleaners. These mechanisms will not be influenced by any of the modern design improvements. Interestingly, the use of the water-activated vacuum cleaner also resulted in an increase in personal allergen exposure, again possibly as a result of the same factors. De Blay et al⁵ also demonstrated a mismatch between experimental chamber data and airborne cat allergen concentrations by using a standard air sampler. However, the use of the NAS in the present study provides a direct measure of personally inspired cat allergen load and thus avoids the criticism of standard air samplers providing more surro-

gate measures of exposure. The disparity between the experimental chamber and allergen exposure in real life means that the use of the experimental chamber alone is insufficient to justify current recommendations of high-efficiency vacuum cleaners to allergy sufferers. Even in the presence of an ever renewable source of allergen, it is conceivable that the long-term use of new HEPA-filter vacuum cleaners could result in the reduction of domestic cat allergen reservoirs. Until there is evidence to this effect, accompanied by a simultaneous reduction in personal cat allergen exposure during vacuum cleaning, claims for the efficacy of these machines in reducing allergen exposure in homes with pets cannot be substantiated. In conclusion, vacuum cleaning with brand-new HEPA-filter vacuum cleaners increases the level of inhaled cat allergen. Cat removal remains the best advice to patients with cat allergy who experience symptoms on exposure and who wish to reduce their exposure.

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