

The effect of high-efficiency and standard vacuum-cleaners on mite, cat and dog allergen levels and clinical progress

Popplewell EJ, Innes VA, Lloyd-Hughes S, Jenkins EL, Khdir K, Bryant TN, Warner JO, Warner JA. The effect of high-efficiency and standard vacuum-cleaners on mite, cat and dog allergen levels and clinical progress. *Pediatr Allergy Immunol* 2000; 11: 142–148. © Munksgaard, 2000

The major triggers for allergic asthma are exposure to allergens of the house dust mite, *Dermatophagoides pteronyssinus*, and of pets. Unfortunately studies of techniques designed to reduce house dust mite and pet allergens have had mixed results. However, new so-called 'improved' products continue to appear on the market and require subjective evaluation. The homes of 60 house dust mite-allergic patients were studied to compare the effects of high-efficiency and standard vacuum-cleaners on allergen concentration. Der p 1 (house dust mite), Fel d 1 (cat) and Can f 1 (dog) allergens were measured in four separate locations in each home. Clinical analysis was by lung function, bronchodilator usage and histamine challenge techniques. There was a significant reduction in Fel d 1 (ng/m²) in dust samples from the living-room carpet ($p = 0.046$), bedroom carpet ($p = 0.003$) and mattress ($p = 0.013$) and living-room sofa ($p = 0.005$) after 12 months of using the high-efficiency cleaners, but only in the mattress sample using the standard cleaners ($p = 0.014$). Can f 1 (ng/g dust) was reduced in the mattress sample after using the high-efficiency vacuum-cleaners ($p = 0.028$), but not at other sites. Der p 1 levels were not significantly changed over this period. Clinically, patients in the high-efficiency group showed improvements in peak expiratory flow rate (PEFR) ($p = 0.004$), FEV₁ ($p = 0.026$) and bronchodilator usage ($p = 0.005$) after 12 months. When the cat-sensitive patients were analyzed separately, improvements in histamine PC₂₀ ($p = 0.039$) were also seen. Reducing Fel d 1 concentrations, in the absence of any change in Der p 1 concentrations, can produce significant improvements in the lung function of atopic, asthmatic patients. This effect was primarily achieved in those patients with cat sensitivity, but who did not possess a cat themselves.

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Key words: asthma; Fel d 1; histamine challenge; lung function; vacuum cleaner; pediatric

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Accepted 10 May 2000

One of the major risk factors for atopic asthma is exposure and sensitization to the house dust mite, *Dermatophagoides pteronyssinus* (1). The numerous studies in allergen avoidance, the majority of which have focused on house dust mite reduction, have had mixed results (2). Some studies concluded that allergen reduction achieved an improvement in clinical symptoms whilst others showed no change in asthma severity. A recently published meta-analysis of controlled trials of house mite avoidance measures suggested that there was no evidence base to recommend such measures (3). There is evidence, however, that

other allergens, such as those produced by cat and dog, may also be important (4).

Effective allergen avoidance is recognized by the International Pediatric Consensus Group as a part of the overall management of atopic asthmatic patients (5). However, total avoidance of inhalant allergens is almost impossible. It has been suggested that a single device is unlikely to be able to achieve sufficient reductions to improve symptoms. The present study therefore targeted three of the main allergen sources found in the home, house dust mite, cat and dog, in a randomized trial of high-efficiency vs. standard

model Electrolux (Luton, Bedfordshire, UK) vacuum-cleaners involving 60 house dust mite-allergic asthmatics studied over a one-year period.

Materials and methods

Study participants

Twenty-one children (age range 5–15 years, median age 11 years) and 39 adults (age range 22–63 years) were recruited from Southampton General Hospital asthma clinics and local GP surgeries between December 1996 and March 1997. All were allergic to house dust mite as assessed by a positive skin prick test (Bencard, Brentford, UK) to *D. pteronyssinus* extract, with a wheal diameter of 3 mm or larger in the presence of no response to a negative control. At recruitment 50 participants (30 adults and 20 children) required regular prophylactic asthma medication and 10 participants (9 adults and 1 child) required bronchodilators only. Fifteen participants owned cats and 10 of these also had a positive skin prick test to cat. Eight participants owned a dog. All were able to perform twice-daily peak expiratory flow rate (PEFR) measurements.

Trial period

After recruitment, patients were randomly assigned to receive one of four Electrolux vacuum-cleaners. Models Z1730 (upright) and Z5028 (cylinder) were classed as high-efficiency vacuum-cleaners and both contained an S-class filtration system (designated HEVa and HEVb). Models Z1501 (upright) and Z2630 (cylinder) were classed as standard models, not containing the

S-class filtration system (designated SVa and SVb). Of the 10 participants who required only bronchodilators, three received cleaner HEVa, two received SVa, three received HEVb and two received cleaner SVb. In the group with cleaner HEVa, four owned a cat and one owned a dog; in group SVa, three owned a cat and three a dog; in group HEVb four owned a cat and one a dog; and in group SVb, four owned a cat and four a dog.

Participants were asked to vacuum-clean the living-room and study patient's bedroom carpet daily and the sofa and patient's mattress at least once a week. Timers were incorporated into the machines without the knowledge of the families to monitor the vacuum-cleaner usage. Homes were visited to collect baseline dust samples in May 1997 (visit 0). Vacuum-cleaners were received in June 1997 and subsequent home visits took place in August 1997 (visit 1), October 1997 (visit 2), January 1998 (visit 3) and May 1998 (visit 4). In December 1997 participants with the HEVa machine had it exchanged for an upgraded Z1740 (HEVc) machine, which was a modified and potentially improved version. The system was the one that the manufacturers wished to market as the definitive allergy-friendly machine and therefore it was more appropriate to assess this version for the study. Dust samples were collected by vacuum-cleaning a m² area with a hand held Dirt Devil vacuum-cleaner (Dirt Devil Ltd, Milton Keynes, UK) fitted with an adapter (ALK, Copenhagen, Denmark) and a filter to trap the dust. A specified m² area on the living-room carpet, sofa, bedroom carpet and bed mattress were vacuum-cleaned for three minutes each using the collecting device. The same areas were used at the subsequent home visits.

Dust samples taken at each of the home visits were weighed and analyzed for the major allergen of house dust mite (Der p 1), cat (Fel d 1) and dog (Can f 1). The results were calculated as ng per gram of dust and ng per m² for each of the four sample places: living-room carpet and sofa, bedroom carpet and mattress.

Allergen analysis

Dust samples were extracted overnight in phosphate-buffered saline (PBS) (pH 7.2) containing 0.05% (v/v) Tween 20 and 0.2% (w/v) bovine serum albumin (BSA). The buffer was added at 1:10 (weight of dust to volume) and filtered the following day with 0.2 µm pore size syringe filters (Whatman, Clifton, NJ, USA). Der p 1 and Fel d 1 were measured using an enzyme-linked immunosorbent assay (ELISA) (Indoor Biotechnologies,

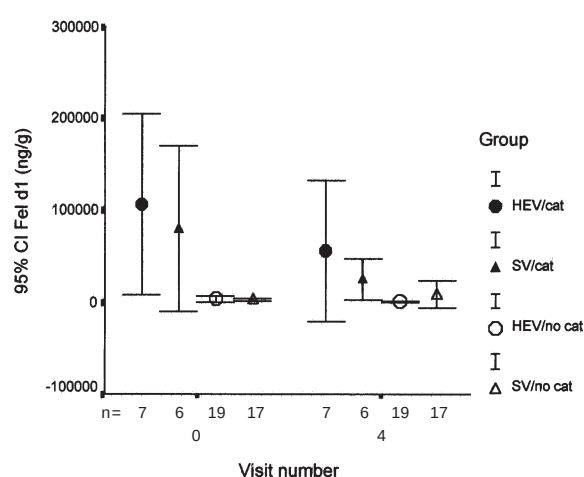


Fig. 1. Graph showing concentrations of Fel d 1 antigen (ng/g dust) in the living-room carpet at the start and end of the study in the homes of patients using HEV and SV cleaners indicating the presence of cats in the home.

Chester, UK) (6). Can f 1 was also measured using an ELISA (Indoor Biotechnologies) (7).

Withdrawals

Over the study period nine patients withdrew from the study. One withdrew between recruitment and visit one, owing to ill health, and two withdrew prior to visit 1 (one moved house and one gave no reason). Two more participants moved out of the area prior to visit two and four more withdrew prior to visit 3 (one moved house and three did not wish to continue with the study but gave no reason). Visit 4 was carried out on 13 patients assigned to the group with cleaner

HEVa/c (86.67%); 15 in group SVa (100%); 13 in group HEVb (86.67%); and 10 in group SVb (66.67%).

Clinical analysis

The severity of asthma was assessed at the start of the study period and after visit 4 with a histamine bronchial challenge. Doubling concentrations of histamine (0.03 mg/ml up to 16 mg/ml) were inhaled for two minutes through calibrated nebulisers and the forced expiratory volume in one second (FEV₁) was measured at 30 s, 90 s and 180 s post-nebuliser (Vitalograph, Buckingham, UK). The PC₂₀ value was extrapolated from the concentration of histamine required to evoke a 20% drop in FEV₁. FEV₁ and PEFR were measured at each of the home visits (Micromedical, Rochester, UK) and the percentage predicted for the age and height calculated (8). Patients also completed diary cards recording bronchodilator usage. The best of three, twice daily, PEFR measurements were recorded before morning and evening medication.

Statistical analysis

All analyses were performed using SPSS version 9.0. Data were not normally distributed, even when the data was logged, therefore the Wilcoxon matched pairs signed rank sum test was used to test for differences between measurements made at baseline and at the final visit. Confidence intervals for the difference were calculated using Confidence Interval Analysis Software (9). It should be noted that it is not possible to calculate exact 95% confidence intervals (10) so the figures quoted are conservative and represent the lowest possible level of confidence over 95%. Clinical data were also analyzed by comparing baseline and visit 4 results and statistical significance was regarded as $p < 0.05$. Vacuum-cleaner groups were also assessed individually in the same way. Analysis was carried out at 12 months and not at the intervening periods as both the allergen and clinical data may be affected by seasonal changes. The data were collected at the intervening periods to encourage participant compliance and to observe what happened over the study period, even though the hypothesis was to evaluate the effect after 12 months.

Results

Change in allergen concentrations in homes: high-efficiency cleaners vs. standard cleaners

For this analysis the results of the HEVa, b and c machines combined were compared with those of

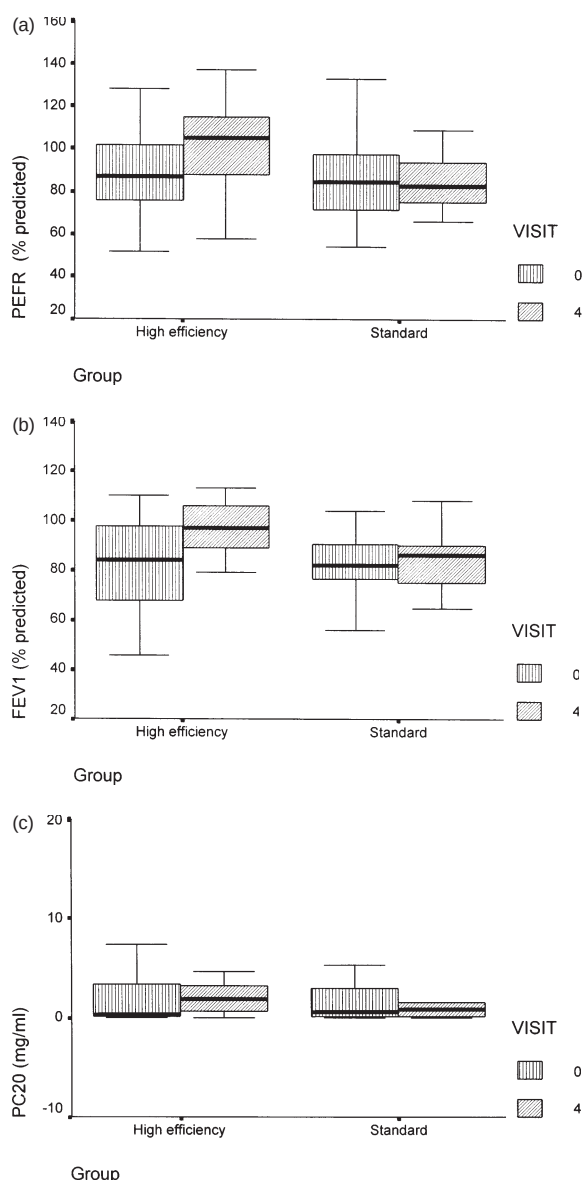


Fig. 2. Box-whisker plot showing clinical parameters measured at the start and end of the study for the whole study population: (a) PEFR (% predicted); (b) FEV₁ (% predicted); (c) PC₂₀ (mg/ml).

Table 1. Median concentrations of (a) Fel d 1, (b) Der p 1 and (c) Can f 1 at the start and end of the study for each location and vacuum-cleaner type. 95% confidence intervals (95% CI) are shown (variability in n is due to insufficient sample for all allergen analyses)

Location	Vacuum-cleaner type	Fel d 1 (ng/m ²) baseline visit	Fel d 1 (ng/m ²) final visit	Median difference	95% CI	n	p-value
Living-room carpet	High-efficiency	735	345	-185	-674 to -15	26	0.046
	Standard	593	292	-261	-712 to 106	23	0.111
Sofa	High-efficiency	1003	495	-728	-3700 to -30	24	0.005
	Standard	980	306	-570	-1647 to 720	23	0.247
Bedroom carpet	High-efficiency	670	144	-193	-68 to -1848	26	0.003
	Standard	603	271	-180	-1320 to -15	23	0.061
Mattress	High-efficiency	1082	203	-491	-1216 to -23	25	0.013
	Standard	1222	152	-580	-1702 to -23	23	0.009

(b)

Location	Vacuum-cleaner type	Der p 1 (ng/m ²) baseline visit	Der p 1 (ng/m ²) final visit	Median difference	95% CI	n	p-value
Living-room carpet	High-efficiency	117	178	117	-2 to 269	26	0.089
	Standard	152	377	64	-12 to 320	23	0.247
Sofa	High-efficiency	443	669	94	-96 to 842	25	0.325
	Standard	109	147	2	-223 to 522	23	0.754
Bedroom carpet	High-efficiency	324	373	10	-375 to 321	26	0.803
	Standard	324	237	19	-278 to 96	23	0.580
Mattress	High-efficiency	521	466	22	-71 to 1264	25	0.179
	Standard	510	256	10	-65 to 1497	23	0.377

(c)

Location	Vacuum-cleaner type	Can f 1 (ng/m ²) baseline visit	Can f 1 (ng/m ²) final visit	Median difference	95% CI	n	p-value
Living-room carpet	High-efficiency	226	143	10	-388 to 203	26	0.958
	Standard	618	109	21	-118 to 2812	22	0.443
Sofa	High-efficiency	883	658	-140	-791 to 469	25	0.542
	Standard	971	309	30	-373 to 2035	23	0.617
Bedroom carpet	High-efficiency	245	87	-78	-258 to 22	25	0.116
	Standard	125	35	-23	-93 to 44	22	0.511
Mattress	High-efficiency	207	97	-58	-726 to -28	25	0.028
	Standard	353	178	-14	-185 to 46	23	0.685

the SVa and b to determine the effect of high-efficiency cleaning vs. standard cleaning. There were no significant differences between baseline allergen concentration for the two groups, high-efficiency and standard models. Twenty-three participants had a usable reading taken from the timer inserted in the vacuum-cleaner. By December 1997, group HEVa had used their vacuum-cleaner for an average of 16.5 h, group SVa for an average of 15.8 h, group HEVb for an average of 17.9 h and group SVb for an average of 19.4 h. This did not result in a statistically significant difference in usage between the HEV and SV groups ($p = 0.548$).

No significant changes between visit 0 and visit 4 were observed in Der p 1 concentration when calculated as ng/g or ng/m² at any sample site in either the HEV or SV group. A reduction in Fel d 1 ng/g was seen in the bedroom carpet ($p = 0.029$), and a reduction in Fel d 1 ng/m² was seen in the living-room carpet ($p = 0.046$),

the bedroom carpet ($p = 0.003$), the mattress ($p = 0.013$) and the sofa ($p = 0.005$) between visit 0 and visit 4 in the HEV group. Fel d 1 ng/m² in the mattress sample was significantly reduced ($p = 0.009$) in the SV group. The groups were also analyzed after being split on the basis of cat ownership. In the homes that contained a cat neither the HEV ($n=7$) nor SV ($n=6$) group showed any reduction in Fel d 1/m², however, Fel d 1/g of dust decreased significantly after 12 months of using the HEVs on the living-room carpet, sofa and bedroom carpet ($p = 0.018$, $p = 0.018$, $p = 0.043$, respectively). In the homes that did not contain a cat, significant reductions were seen in both Fel d 1/m² and Fel d 1/g of dust at all sample sites in the HEV group ($n=19$) and in the sofa, bedroom carpet and mattress of the SV group ($n=17$). Figure 1 shows Fel d 1 concentrations per gram of dust in the living-room carpet at baseline and at the final visit for both the HEV and SV groups with an indication of

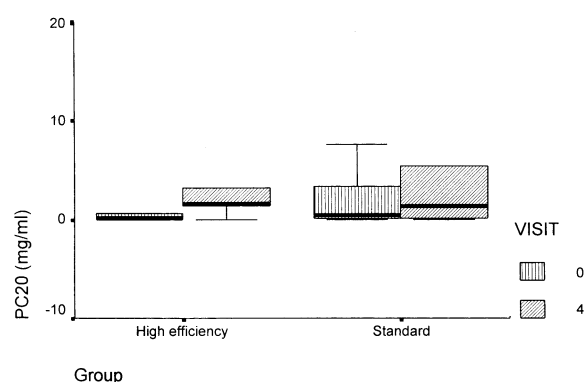


Fig. 3. Box-whisker plot showing PC₂₀ (mg/ml) at the start and end of the study for the cat-sensitive study group.

whether a cat was present in the home. Table 1 shows Der p 1, Fel d 1 and Can f 1 concentrations (ng/m²) for visit 0 and visit 4 in the HEV and SV groups.

To assess effectiveness of individual cleaners, results were analyzed by group. There was no significant difference between the groups at baseline. No cleaner showed a significant change between visit 0 and visit 4 in either Der p 1 per gram or per m² in any sample place.

No significant reduction was seen in the concentration of Fel d 1 (ng/g) at any site with any vacuum-cleaner between visit 0 and visit 4, however, vacuum-cleaner HEVb showed a significant reduction in Fel d 1 when calculated as ng/m² in three out of the four sample sites: sofa ($p = 0.045$), bedroom carpet ($p = 0.014$) and mattress sample ($p = 0.019$). No significant reduction was seen for any of the other vacuum-cleaners at any other site when calculated as ng/m².

No significant reduction in Can f 1 was observed at any sample site between visit 0 and visit 4 when expressed as ng/g of dust. When calculated as ng/m², a significant reduction was seen in the dust sample taken from the mattress ($p = 0.041$) in HEVb. No significant reduction was seen at any other sample site.

Clinical data

Clinical data were compared in the high-efficiency models (HEVa/c and b) and the two standard models (SVa and SVb) and also in all vacuum-cleaner groups individually using a Mann-Whitney Wilcoxon Rank Sum test. By visit 4 there was a significant difference in PEFr ($p = 0.001$) and FEV₁ ($p = 0.027$) between the HEV and SV groups. In the HEV group, PEFr improved from 87% of

predicted for age and height (range 52–128%) to 105% (range 58–137%) ($p = 0.004$). FEV₁ increased from 84% (range 46–110%) to 97% (range 43–113%) ($p = 0.026$) between visit 0 and visit 4. PC₂₀ increased from 0.38 mg/ml (range 0–7.37 mg/ml) to 1.895 mg/ml (range 0.007–16.11 mg/ml) although this increase was not significant ($p = 0.143$). The SV group showed no significant change in PEFr ($p = 0.912$), FEV₁ ($p = 0.806$) or PC₂₀ ($p = 0.931$) between visit 0 and visit 4. Figure 2 shows PEFr, FEV₁ (both expressed as per cent predicted) and PC₂₀ for HEV and SV groups at visit 0 and visit 4. Bronchodilator usage was reduced when comparing the run-in data with the two weeks prior to the end of the trial in the HEV group ($p = 0.005$), but not in the SV group ($p = 0.400$).

Clinical changes were also assessed in the individual vacuum-cleaner groups. PEFr showed a significant improvement ($p = 0.01$) in the group with cleaner HEVb and a trend in improvement in cleaner group HEVa/c ($p = 0.073$) between visit 0 and visit 4. Participants placed in the groups with SVa or SVb cleaners showed no change in either PEFr or FEV₁. PC₂₀ showed no significant change between visit 0 and visit 4 in any of the individual vacuum-cleaner groups.

It was hypothesized that the significant clinical improvement seen in lung function could be due to the decrease in Fel d 1 levels, so the data were reanalyzed including only those patients with a positive skin prick test to cat ($n = 16$ in the HEV group; $n = 13$ in the SV group). They were initially recruited on the criteria of house dust mite allergy and not on their cat-allergic status. The HEV group data were compared at start and end points of the study. PEFr showed an increase from 87% (range 66–124%) to 106% (range 80–133%) ($p = 0.015$). FEV₁ increased from 82% (range 55–110%) to 101% (range 56–113%) ($p = 0.033$) and PC₂₀ increased from 0.27 mg/ml (range 0–7.37 mg/ml) to 2.405 (range 0.7–16.11 mg/ml) ($p = 0.039$) (Fig. 3). When the results of the HEV group were analyzed by whether the patients had a cat or not, significant changes were seen in the non-cat-owning group and not in the cat-owning group. The SV group showed no significant changes. Individual cleaner groups were not compared because of the small numbers of participants in each group. Those with a negative skin prick test to cats ($n = 5$ in the high-efficiency group; $n = 3$ in the standard group) showed no significant change in PEFr, FEV₁ or PC₂₀ between the start and end of the study.

Discussion

The aim of the present study was to assess whether using a high-efficiency vacuum-cleaner in the home would reduce house dust mite and pet allergen levels in carpets and soft furnishings. It was hoped that a reduction in allergen levels would produce an improvement in asthma symptoms in house dust mite-allergic participants. However, Der p 1 levels in the homes were not significantly reduced by either the high-efficiency or standard model of vacuum-cleaner at any of the sites. Recently a meta-analysis of 23 studies aimed at reduction of house dust mite allergen concluded that the chemical and physical methods used for eradicating mites in these studies were not capable of producing an improvement in clinical symptoms (3). It must be noted that the majority of measures analyzed were not able to significantly reduce mite allergen concentrations and were therefore highly unlikely to result in a change of symptoms. The vacuum-cleaners in the present study were also unable to significantly reduce Der p 1 concentrations and therefore in future other methods that are more successful in Der p 1 reduction need to be evaluated clinically.

However, despite the lack of success with the hypothesis concerning dust mite allergens, another highly interesting, and potentially very important, finding was made. It has been reported by other groups that vacuum-cleaners with built-in HEPA filters, when used with double-thickness bags, can remove allergen without leaking Fel d 1 or Can f 1 (11, 12). Use of a vacuum-cleaner with integral HEPA filter and double-thickness bags is one of the recommendations for reducing cat/dog allergen exposure (13). The participants in this study who were given HEVs containing S-class filter systems had significantly reduced levels of Fel d 1/m² in all of the sample sites in their homes after one year of use. This uniform reduction was not seen in the SV group, although a reduction was seen in the mattress samples. Fifteen of the homes contained a cat, and while all homes contained measurable levels of Fel d 1, it was very clear that the presence of a cat in the house presented the cleaners with a much more difficult task. Interestingly, in the homes with a cat, the HEVs reduced Fel d 1/g of dust, but not Fel d 1/m² of area sampled, indicating that the actual concentration of the allergen in the dust was being reduced. This could be due to dust from deeper in the source materials being removed, rather than just the surface dust (the surface allergen would be replaced rapidly whenever the cat sat on the source material). The SVs were unable to show

any reduction in Fel d 1 when a cat was present. In the homes without a cat, both types of cleaners produced reductions in Fel d 1/g and Fel d 1/m², but the HEVs were more consistent in their effect. This has important implications for cat-sensitive patients who take care to avoid cats. Use of one of these HEVs in their homes will reduce their passive exposure to cat allergen significantly. When individual cleaners were assessed, it was the group with the cylinder HEV that had the greatest reduction in Fel d 1 levels. This would therefore be the cleaner of choice, if asked for a recommendation.

The notable effect on Fel d 1 was unfortunately not reproduced on the dog allergen Can f 1. This may be due to some different characteristic of the two allergens, but both are highly ubiquitous and can potentially cause increased symptoms in pet-sensitive subjects owing to passive exposure in public places (14). It would be worth manufacturers considering whether it might be possible to improve the Can f 1 pick-up of their machines to complement the Fel d 1 collection. Fewer asthmatic individuals are allergic to dogs than cats, but they are still a major trigger of allergic diseases.

Despite the failure to significantly reduce Der p 1 concentrations, the HDM-sensitive patients with a HEV still showed an improvement in clinical symptoms (FEV₁ and PEF_R). This suggested that another factor influenced improvement and we believe that the reduction in symptoms was due to the reduction in Fel d 1 levels.

The clinical benefits of reducing pet allergen in the home have not been fully established, but a study of cat-owning, cat-allergic, rhinitis patients found that environmental control that resulted in the reduction of Fel d 1, combined with the use of nasal steroids, was associated with significant clinical improvement (15).

When the subgroup of participants in this study who were cat-sensitive as well as house dust mite-sensitive was analyzed separately, the improvement in PC₂₀ became significant in the HEV group, as well as the lung function measurements. However, no effect was observed in those with house dust mite but not cat allergy. Therefore, the reduction of the cat allergen Fel d 1 in homes results in significant benefit to cat-allergic asthmatic patients. Cat-allergic asthmatic patients should also avoid passive exposure to cat allergen in their homes, even if they are not cat owners. Regular use of a HEV in the homes of these patients can be recommended to improve symptoms, although if there is cat present in the home asthma symptoms do not improve despite a reduction in Fel d 1. Other allergen-reduction

techniques (such as washing the cat) may need to be added to vacuuming, if the cat is *in situ*, before symptoms improve.

Total avoidance of pet allergens in many geographical areas is virtually impossible, as patients are not only exposed in the home, even if they don't own a pet, but also in public buildings and on public transport (14, 16). Allergen avoidance in the home is, however, a valuable starting point in reducing total allergen exposure.

Further studies on allergen avoidance are needed with the emphasis being on reduction of cat allergen rather than house dust mite. The effect of reduction in dog allergen deserves investigation.

Further clinical studies are required to investigate the possibility of combining HEVs with other Fel d 1-reducing techniques in the home to create a more significant effect. This is important to determine whether, in homes where there are cat-sensitive asthmatic individuals cohabiting with a cat, Fel d 1 can be reduced sufficiently to result in a similar clinical improvement to that reported here in non-cat-owning but cat-allergic asthmatic individuals.

Acknowledgments

The authors would like to thank Dr Peter Howarth for allowing some of his patients to take part in the study. Dr Peter Standring, Dr Maria Moustaki, Kate Brydon and Elizabeth Friend all provided clinical expertise in performing histamine challenges. Dr Jill Warner was funded by The British Lung Foundation/National Asthma Campaign Senior Fellowship into Asthma and the Environment. Eleanor Popplewell was funded by Electrolux and The British Allergy Foundation provided funding for studies into the removal of cat allergen from the domestic environment.

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