

Allergens in school dust

I. The amount of the major cat (*Fel d I*) and dog (*Can f I*) allergens in dust from Swedish schools is high enough to probably cause perennial symptoms in most children with asthma who are sensitized to cat and dog

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Background: We investigated the levels of *Fel d I* and *Can f I* in dust from tables, chairs, and floors in 29 classrooms in four Swedish schools.

Methods: School authorities were questioned about building characteristics, students were interviewed about their health and exposure to animals, and cleaning personnel were asked about methods and frequency of cleaning. Dust samples were taken from floors and horizontal surfaces of chairs and tables in all classrooms during a 6-week period.

Results: Higher amounts of *Fel d I* were found on chairs (geometric mean, 953 ng per gram of dust) than on tables (525 ng/gm) and floors (134 ng/gm). The concentration of *Can f I* (5.3 ng/gm) on chairs was 2 to 20 times higher than *Fel d I*. The concentration of *Can f I* (200 ng/gm) in dust from floors was twice as high as that of *Fel d I*. The concentration of *Can f I* on chairs was within the range previously found by other investigators in houses with dogs.

Conclusions: Since the levels of both *Fel d I* and *Can f I* were much higher on chairs than on floors, we hypothesize that allergen is brought to schools on the clothes of students and teachers. We conclude that the levels of the two major allergens from furred pets (i.e., *Fel d I* and *Can f I*) in Swedish schools are probably high enough to sensitize children and to induce asthma in most children who are allergic to cats or dogs. (*J ALLERGY CLIN IMMUNOL* 1993;91:1067-74.)

Key words: *Can f I*, ELISA, *Fel d I*, school dust

More than 50% of Swedish school children keep furred pets at home.¹ It has been estimated that 70% of Scandinavian children with perennial asthma are sensitized to dog and/or cat dander as determined by skin prick test, conjunctival provocation test, and in vitro tests.²⁻⁴ Many of these

Abbreviations used

BPT: Bronchial provocation test
BU: Biologic units (according to the Nordic Guidelines)

Can f I: Major dog allergen from *Canis familiaris*

Fel d I: Major cat allergen from *Felis domesticus*

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children have chronic asthma, even without having contact with the allergens in question. Thus a cause-effect relationship is often not obvious.

Contact with an allergen source may cause not only immediate symptoms of asthma, but also a prolonged period of bronchial hyperreactivity, which may last for weeks.⁵ Connell⁶ showed that repeated exposure of the nasal mucosa to low doses of allergen caused symptoms similar to

TABLE I. Technical characteristics of schools and classrooms investigated

	School 1	School 2	School 3	School 4
School location				
Urban	Yes	No	No	Yes
Rural	No	Yes	Yes	No
Total no. of classrooms/school	37	17	9	15
No. of classrooms investigated	6	8	7	8
No. of pupils/school	573	634	233	260
Classroom located on				
Ground floor	3	3	No	8
Upper floor	3	5	7	No
Type of ventilation system				
Windows	Yes	Yes	Yes	Yes
Passive by ventilator	Yes	Yes	Yes	No
Active outblowing by fan	No	Yes	Yes	Yes
Daytime	No	Yes	Yes	Yes
Nighttime	No	Yes	No	Yes
Weekends	No	No	No	Yes

allergic rhinitis, and Ihre and Zetterström⁷ showed that daily inhalation of only 1% of the allergen dose that caused immediate symptoms for 1 week induced bronchial hyperreactivity.

In cat-sensitive patients, 8 µg of the major allergen of cat dander, *Fel d I*, per gram of fine dust has been found to be a risk factor for acute asthma.⁸

Many children who are allergic to cats and dogs do not have a pet at home, and there is no obvious source of allergen in their environment. Furthermore, children with asthma who are sensitized to animal allergens frequently experience worsening of their symptoms when they return to school after vacations. This has been ascribed to exposure to school dust that contains cat and dog allergens brought to schools on the clothes of students with household pets.

The aim of the present study was to investigate the levels of *Fel d I* and *Can f I* in school dust and to relate these to some characteristics of the school buildings and to the exposure of students and teachers to pets.

METHODS

School buildings and classrooms

Administrators and school authorities were asked to respond to a questionnaire regarding the four school buildings. Some technical characteristics of the school buildings and classrooms are given in Table I. Twenty-nine classrooms in the four schools were investigated. All schools and classrooms were chosen at random. Chair surfaces were made of wood or plastic (for students) or upholstery (for teachers). Schools were randomly numbered from 1 to 4.

Characteristics of teachers and students

Questions regarding the health of students and their exposure to animals were answered by the students, who raised their hands in response to questions from the nurse, who then completed the questionnaires. Teachers were interviewed by the school nurses regarding their health and exposure to pets. Some characteristics of students and teachers are given in Table II.

Cleaning methods

The personnel responsible for cleaning of the classrooms were given a questionnaire about the cleaning methods used. In two schools the chair surfaces were cleaned and in two they were not (Table II). The tables and floors were cleaned one to three times a week in all the schools by means of either dry sweeping or wet sweeping with a detergent.

Dust sampling

Dust was sampled from all classrooms from October 1 to November 20, 1990. Table, chair, and floor surfaces were cleaned according to the routine cleaning schedule, and no changes were made before sampling. Dust was sampled from floors and horizontal parts of chairs and tables in the classrooms. A surface of 5 m² was vacuumed for 5 minutes with a special device that contained a Millipore filter (pore size, 6 µm) (Allergologisk Laboratories, Copenhagen, Denmark), which was connected to a Volta vacuum cleaner (series 250, 1100 kW; Electrolux, Stockholm, Sweden). Dust was sampled in 14 classrooms on Monday morning by one team and in 15 other classrooms on Friday morning by another team. In both cases sampling was done between 6 and 8 AM (i.e., before students arrived). Dust samples were stored at -20° C until analyzed. The amount of dust collected from table surfaces was not sufficient for analysis of dog allergen (*Can f I*).

TABLE II. Characteristics of pupils and teachers working in the classrooms and cleaning methods

	Number per classroom											
	School 1		School 2		School 3		School 4					
No. of pupils, mean (range)	20 (14-27)		23 (20-27)		22 (15-26)		22 (18-29)					
No. of teachers = 1-2	6		6		5		8					
= 3-4	ND		2		2		ND					
	Number per teachers/pupils											
	Teacher(s)	Pupils	Teacher(s)	Pupils	Teacher(s)	Pupils	Teacher(s)	Pupils				
Cat at home	3	11	2	54	1	66	1	34				
Dog at home	1	13	0	37	0	51	1	24				
Frequent contacts with cat	1	23	2	48	2	60	1	55				
Frequent contacts with dog	2	30	1	61	1	63	1	62				
Cat at home (total)	3/6	11/120	2/8	54/184	1/7	66/154	1/8	34/176				
Dog at home (total)	1/6	13/120	0/8	37/184	0/7	51/154	1/8	24/176				
	Cleaning methods											
	Table	Chair	Floor	Table	Chair	Floor	Table	Chair	Floor	Table	Chair	Floor
Cleaning includes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes
Dry sweeping (times/week)	ND	1	3	ND	ND	ND	ND	ND	ND	1	ND	3†
Wet sweeping (times/week)	1	ND	ND	3	ND	3	1	1	3	1	ND	‡
Detergent*	ND	ND	Yes	Yes	ND	Yes	Yes	Yes	Yes	ND	ND	Yes

ND, Not done.

*Allrent (Euroclean AB, Åtvidaberg, Sweden), soap and water, and/or Trippel (Euroclean AB).

†Alternate weeks.

‡Several times a year.

Processing and extraction of dust

Dust particles were separated from the filter by shaking and scraping and were then passed through a sieve with a porosity of 300 μ m to obtain the fine dust. Dust particles were between >6 μ m and 300 μ m size. Sieved dust was removed and weighed. Dust from table and chair surfaces was more voluminous and floppy than dust from floor surfaces. The average weight of sieved dust was 15 mg, 888 mg, and 565 mg from table, chair, and floor surfaces, respectively. The range of dust weight on table surfaces was between 9 mg and 75 mg; on chair surfaces, between 313 mg and 1734 mg; and on floor surfaces, between 173 mg and 1304 mg.

Dust extracts were prepared with an extraction ratio of 1:10 (weight per volume) by dissolving the samples in phosphate-buffered saline (pH 7.6) overnight at +4° C under constant rotation. Extracts were clarified by centrifugation twice at 3500 rpm (average) for 20 minutes and then stored at -20° C until analyzed. All extracted dust samples were from the same schools and classrooms for analysis of *Fel d I* and *Can f I*.

Determination of major allergen content

The concentration of major cat and dog allergens in school dust was determined by sandwich ELISA according to the method described by Chapman et al.⁹ for *Fel d I* and the method described by Schou et al.¹⁰ for *Can f I*.

The ELISA test kit for *Fel d I* was kindly supplied by Dr. M. D. Chapman (Charlottesville, Va.). The kit was based on a monoclonal antibody towards *Fel d I* (clone 6F9 A4-H1) and a second monoclonal biotinylated antibody towards *Fel d I* (clone 3E4 C4-C10). Reference preparation of *Fel d I* (10.5 U/ml) was kindly supplied by the Office of Biologics, Food and Drug Administration (Bethesda, Md.).

For *Can f I* ELISA, both capture and detection layers of antibody to *Can f I* were monospecific rabbit antibody. The detection antibody was peroxidase-labeled, and reference preparation of *Can f I* was prepared by Schou et al.¹⁰

The interassay variation for repeated assays was 14% and the intraassay variation was 6.5% for *Fel d I*. Both

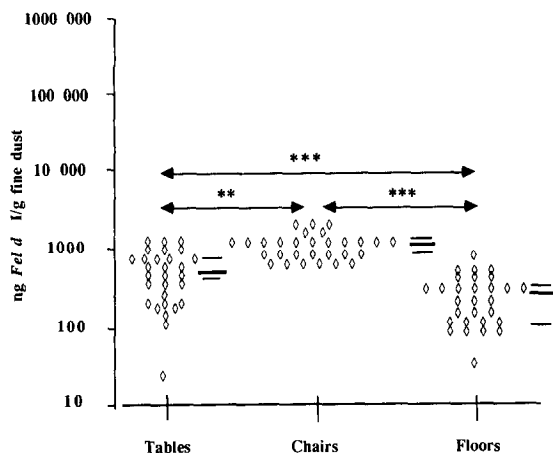


FIG. 1. *Fel d I* (nanograms per gram of fine dust) from tables, chairs, and floors in 29 classrooms from four schools. The median and 95% confidence intervals are given. ** $p < 0.01$; *** $p < 0.001$.

interassay and intraassay variation of the *Can f I* assay were less than 6%. The lower detection limit was 0.4 mU/ml for *Fel d I*, which corresponds to 16 ng per gram of fine dust, and 6 ng/ml for *Can f I*, which corresponds to 60 ng per gram of fine dust.

The total amount of *Fel d I* or *Can f I* was calculated from the total surface area of tables, chairs, and floors. The total amount is the reservoir of *Fel d I* and *Can f I* allergens per sampling area of tables, chairs, and floors.

Statistical analysis

Student's *t* test and factorial analysis of variance ANOVA techniques were used to test the level of significance between variables with $p < 0.05$ and $p < 0.001$ as the lowest and highest levels of significance. We also analyzed the data with simple linear regression procedure to determine how covarying variables were associated with different sources and environmental parameters.

RESULTS

Characteristics of students, teachers, and school buildings

The number of teachers and students who had daily direct or frequent contact with pets (i.e., cats and dogs) was higher in schools 2 and 3. These schools were located in rural areas (Tables I and II). The highest concentrations of both *Fel d I* (geometric mean for tables, chairs, and floors together = 1774 ng/gm) and *Can f I* (geometric mean for chairs and floors together = 9 μ g/gm) were recorded in school 3. This school had the greatest number of students and teachers with pets at home (Table II).

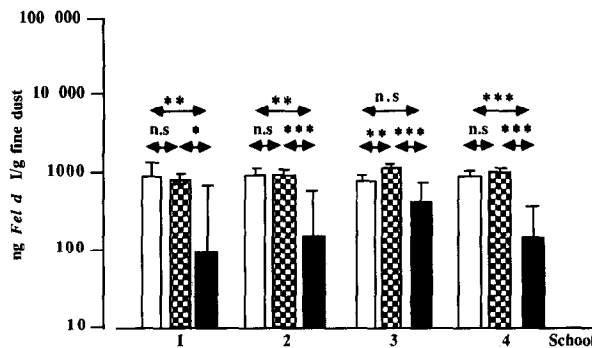


FIG. 2. *Fel d I* (nanograms per gram of fine dust) from tables, chairs, and floors in four schools. The median and 95% confidence intervals are given. □, Table; ▨, chair; ■, floor; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; n.s., non-significant.

Cat allergen

Cat allergen was present in all of the classrooms. Only one dust sample from the floor was below the detection limit of the ELISA assay (i.e., 16 ng/per gram of fine dust). Eighteen percent of the samples, 13% from chairs and 5% from table surfaces, contained $> 1 \mu$ g of *Fel d I* per gram of fine dust. The concentration of *Fel d I* in the dust collected from the horizontal surfaces of chairs, tables, and floors in the four schools and their ranges are shown in Fig. 1. The concentration was higher on chairs (geometric mean, 953 ng/gm; range, 632 to 1626 ng/per gram of dust) than on tables (geometric mean, 525 ng/gm; range, 29 to 1579 ng/per gram of dust) ($p < 0.01$) and floors (geometric mean, 134 ng/gm; range, < 16 to 567 ng/per gram of fine dust) ($p < 0.001$). The concentration on chairs did not correlate with that on tables ($r = 0.2$) or floors ($r = 0.14$).

Fig. 2 demonstrates the concentration of *Fel d I* on the different surfaces in the four different schools. The concentration of *Fel d I* did not differ significantly between tables and chairs ($p = 0.06$ to 0.28) except in school 3 ($p < 0.01$). However, in all classrooms the concentration in the floor dust was lower ($p < 0.01$) than that on tables and chairs.

The concentration of *Fel d I* on the chair surfaces correlated ($r = 0.4$; $p < 0.05$) with the number of teachers and students who had cats at home or who had frequent contact with cats. Dust from classrooms with a higher number of students and teachers who had cats at home or who had frequent contact with cats contained higher concentrations of cat allergen than those used by persons who had less contact with pets, but this

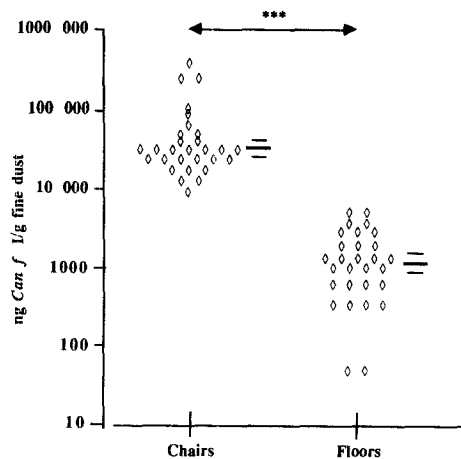


FIG. 3. *Can f I* (micrograms per gram of fine dust) from chairs and floors in 29 classrooms from four schools. The median and 95% confidence intervals are given. *** $p < 0.001$.

difference was not significant for any of the three types of surfaces investigated.

The concentrations were higher on chairs in classrooms located on the second floor of the school buildings as compared with those on the ground and first floors ($p < 0.01$). More teachers and students who had cats at home or who had frequent contact with cats worked on the upper floors than on the ground floor ($n = 220$ and 144 ; $p < 0.01$).

Type of ventilation was not associated with the concentration of *Fel d I* in the classrooms. The concentrations of dust sampled on Monday and Friday mornings were similar.

The cleaning frequency in schools was similar (Table II), but the procedures differed. The concentrations of allergen were significantly lower ($p < 0.05$) on chairs and floors in schools 2 and 3 where wet sweeping was used than in the other two schools. There was no difference in allergen concentration on the horizontal surfaces of chairs whether they were included in the cleaning procedure or not. However, dry cleaning of the chair surfaces significantly ($p < 0.01$; $n = 13$) reduced the concentration of allergen, as compared with wet cleaning. Significantly ($p < 0.01$; $n = 13$) lower concentrations of *Fel d I* were found in floor dust in classrooms cleaned by both dry and wet cleaning compared with those classrooms that were cleaned by only wet cleaning.

The total amount of *Fel d I* per sampling area of tables, chairs, and floors correlated ($r = 0.5$; $p < 0.01$) with the number of students and teachers who had cats at home. However, this associa-

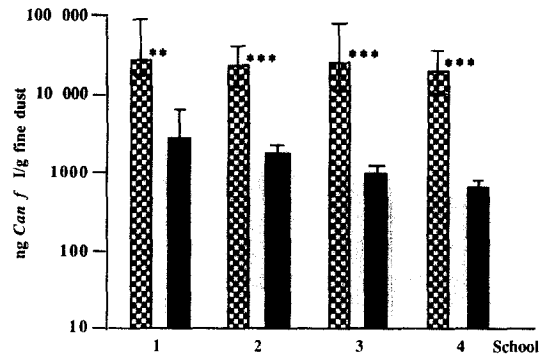


FIG. 4. *Can f I* (micrograms per gram of fine dust) from chairs and floors in four schools. There were no differences between chairs or between floors in the four schools. The median and 95% confidence intervals are given. ▨, Chair; ■, floor; ** $p < 0.01$; *** $p < 0.001$.

tion did not exist ($r = 0.3$, NS) when teachers and students who had cats at home and who had frequent contacts with cats were grouped together (Table II).

Dog allergen

Can f I allergen was detected in all samples but two from floors. The concentrations varied widely and were particularly high on the chairs (Fig. 3), (geometric mean, $5.3 \mu\text{g}$ per gram of fine dust; range, 1.7 to $28.2 \mu\text{g/gm}$). Only one sample from a chair surface had a concentration less than $2 \mu\text{g/gm}$ ($1.7 \mu\text{g}$). Twenty-three of the chair samples contained *Can f I* between 2 and $10 \mu\text{g/gm}$ and five more than $10 \mu\text{g/gm}$ per gram of fine dust. The concentration of *Can f I* was lower in floor dust (geometric mean, 200 ng/gm per gram of fine dust; range, 56 to 506 ng/gm). Chair surfaces contained significantly higher ($p < 0.001$) concentrations of allergen than floors. The concentrations on chairs and floors did not correlate.

The concentrations of *Fel d I* and *Can f I* on chair surfaces correlated in all schools ($r = 0.4$ to 0.5 ; $p = \text{NS}$) except school 3. On floor surfaces a significant correlation was observed in schools 2 and 4 ($r = 0.8$; $p < 0.05$) but not in schools 1 and 3. There was a weak correlation ($r = 0.3$; $p = \text{NS}$) when all the classrooms were considered.

Fig. 4 demonstrates the concentrations of *Can f I* allergen found in dust from chairs and floors in the four schools. In all schools the concentration of dog allergen was significantly higher ($p < 0.01$ to < 0.001) on chairs than on floors. The highest concentration of *Can f I* was recorded on chairs (geometric mean, $8.8 \mu\text{g}$ per gram of dust) in school 3, a school located in a rural area. The

concentrations of *Can f* I on chairs and floors correlated in all schools ($r = 0.4$ to 0.7 , NS) except school 2 ($r = 0.1$, NS). There was no correlation ($r = 0.2$, NS) when all the classrooms were considered.

The allergen concentrations were not significantly influenced by the technical characteristics of schools and classrooms listed in Table I. Type of ventilation had no influence on the concentration of *Can f* I. In schools with a ventilation system working during the day and at night, the concentration of *Can f* I was significantly lower ($p < 0.05$) than in classrooms with a ventilation system working only during daytime.

The number of teachers had a significant impact on the concentration of *Can f* I allergen in school dust. In classrooms where at least three teachers worked, higher concentrations of dog allergen were found as compared with classrooms with fewer teachers ($p < 0.05$). The concentration of dog allergen tended to be higher in classrooms with many students and teachers who had dogs at home or who had frequent contact with dogs, but this did not reach statistical significance.

The concentration of dog allergen was not affected by dry and wet cleaning of floors. In contrast, in classrooms where either dry or wet cleaning was applied to chair surfaces, the concentration of dog allergen was significantly higher ($p < 0.05$) than in classrooms in which chairs were never cleaned. In one of these schools 74% of students had dogs at home or had frequent contact with dogs (school 3).

The number of students and teachers with dogs at home did not correlate ($r = 0.1$, NS) with the total amount of *Can f* I per sampling area of tables, chairs, and floors, nor was there an association ($r = 0.2$, NS) when the number of teachers and students who had dogs at home and who had frequent contact with dogs were grouped together.

DISCUSSION

The amount of the major cat allergen, *Fel d* I, in Swedish school dust was similar to that found in Michigan public places¹¹ and in homes without cats.¹² The *Fel d* I concentrations were much lower than in homes in which cats were kept as reported by Miller et al.¹³ but similar to some homes with cats, as found by Munir et al.¹⁴ and Swanson et al.¹⁵

Our study shows that the concentration of *Can f* I in Swedish schools is remarkably high. In fact, it was as high as in households with dogs in the

United States.¹⁰ In that study Schou et al.¹⁰ found that 50% of households with dogs had less than 24 μg *Can f* I per gram of dust (range, 2 to 2000 μg per gram of dust)* and about 50% of households without dogs had more than 600 ng *Can f* I per gram of dust (range, 60 ng to 4.6 μg per gram of dust). We confirm that the *Can f* I and *Fel d* I¹¹ levels were high, even in places where dogs or cats had no access. This could explain why removal of pets from homes usually does not lead to the anticipated decrease in symptoms.

The higher levels of *Fel d* I and *Can f* I allergens on the horizontal surfaces of chairs than on tables and floors might be the result of children and teachers carrying cat and dog dander on their clothing, which transfers the dander particles to the chairs. The hypothesis by Shamie et al.¹¹ "antigen is dispersed causally from the populations clothing" is supported by our data.

In general, schools had higher concentrations of *Fel d* I and *Can f* I on chairs than on floors. Our hypothesis is that the chair surfaces were contaminated by *Fel d* I and *Can f* I from the clothes of children who keep cats and dogs as pets. The concentration of allergens on floors was reduced by cleaning, and the concentration was further reduced by dilution with other particles.

The concentration of *Can f* I was 2 to 20 times higher than that of *Fel d* I. A possible explanation might be that school children are in closer contact and in contact for longer periods with dogs than with cats, since dogs are more often close friends to children.

The chair surfaces were cleaned on a regular basis in only two of the schools. Surprisingly, chairs that were never cleaned showed lower concentrations of *Fel d* I and *Can f* I allergen than those that were cleaned often; this might be because the number of students and teachers who had cats and dogs at home or who had contact with cats and dogs was lower in these classrooms.

The cat allergen concentration was higher on chair surfaces in classrooms located on the upper floors than in those on the ground floors. This might be explained by the greater number of teachers and students who had cats at home and who had frequent contact with cats working in the upper floors than in the ground floors. The find-

*In the reference, values that are five times higher are given. However, since then, the potency of the reference preparation has been reevaluated and corrected.

ings indicate that the amount of *Fel d* I in schools is not related to the technical characteristics of the schools and classrooms but depends on contacts of students and teachers with pets.

We found higher levels of *Fel d* I allergen concentration in dust collected from tables and chairs than in that collected from floors in all but one of the schools investigated. The floor surfaces were swept daily; tables were swept once or twice a week; and surprisingly, in some schools (schools 2 and 4), chair surfaces were not cleaned on a weekly basis. Thus once the chair had been brought to the classroom, it was not cleaned until the main cleaning during the summer holidays. Thus chair surfaces act as a reservoir of allergens. This should be considered when the cleaning procedure is modified to reduce the allergen load. We calculated the total amount of allergen per sampling area of tables, chairs, and floors. This may be a more suitable measure of allergen load than the concentration of allergen.

The dose for induction of cat-induced asthma has been reported by Van Metre et al.¹⁶ They found that 56 ng of cat allergen *Fel d* I in inspired ambient air induced a 20% fall forced expiratory volume in 1 second. In another study Ohman et al.¹⁷ found that between 8 and 80 ng of *Fel d* I nebulized during 2 minutes induced positive results of bronchoprovocation test (BPT) and Dreborg¹⁸ found that the most sensitive individuals react to inhalation via a nebulizer of less than 1 biologic unit (BU) (i.e., less than 1 ng of major allergen).¹⁹ It has also been shown that it would take only 12 minutes to inhale 8 ng of airborne *Fel d* I from disturbed air in a house with a cat²⁰; that is, less than 1 ng is inhaled per minute. This corresponds roughly to the amount inhaled by sensitive patients in BPTs. Furthermore, in homes with cats, Swanson et al.¹⁵ found 1.2 µg of *Fel d* I per gram of fine dust and 1.4 ng/m³; the relationship between the concentration of cat allergen per gram of fine dust and that per cubic meter of air was about 1000-fold as confirmed by Luczynska et al.²⁰ Thus about a half of 1 ng is inhaled per hour in Swedish schools with 1 µg of *Fel d* I per gram of dust, provided that a student has a minute ventilation of about 10 L/min. Whether dog allergen is airborne to the same extent as cat allergen remains to be investigated.

There is at least a 10,000-fold difference in sensitivity in the skin,²¹ the conjunctiva,²² and the bronchi¹⁸ of patients who are sensitive to the same allergen and who are referred to a university

clinic. In the general population the variation in sensitivity is more than a million-fold.²³ In BPTs the most sensitive patients react to 1 BU/ml, and the mode of the distribution of sensitivities is about 1000 to 3200 BU/ml.¹⁸ Recently, it has been shown that the major allergen content is similar in biologically standardized allergenic extracts from different allergen source materials. It was reported that 1 BU of the most common inhalant allergens corresponds roughly to about 1 ng of major allergen.¹⁹ Thus the most sensitive patients with asthma react to 1 ng of major allergen inhaled within 1 minute. On the other hand, the least sensitive patients do not react before they have inhaled 1 mg of major allergen (i.e., have been exposed for a longer period of time).

Ilhré and Zetterström⁷ have demonstrated that daily inhalation for 1 week of 1% of the allergen dose that causes positive results of BPT induced bronchial hyperreactivity; that is, the most sensitive patient reacts immediately to inhalation of 100 pg of major allergen but to 10 pg daily during 1 week. This means inhalation of less than 0.01 pg/min, which corresponds to 10 pg/gm of fine dust. Thus on the basis of the relationship between dust and air concentrations of cat allergen, variation in sensitivity among patients, and concentrations of *Fel d* I found in school dust, it is suggested that the levels found in all of our samples are sufficiently high to cause at least low-grade clinical asthma in most cat-sensitive children with asthma who attend Swedish schools.²⁴

So far, risk levels for *Can f* I in dust inducing sensitization and asthmatic symptoms have not been defined. The clinical significance of dog allergen exposure remains to be investigated.

Finally, our results provide a probable explanation as to why the prevalence of cat and dog allergy is high^{2, 4} in our area and why children who are allergic to animal dander show continuous severe asthma without known contact with pets. It seems to be important to reduce cat and dog allergen levels both in homes and schools in order to prevent sensitization to pets and reduce symptoms in children who are already allergic to pets.

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