

Determinants of house dust mite allergen in homes in Wellington, New Zealand

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Summary

Objectives To measure levels of the major *Dermatophagoides pteronyssinus* allergen (Der p 1) in homes in Wellington, New Zealand, and to examine factors which affect these levels.

Methods As part of a study of risk factors for asthma among 474 8–10-year-old children, standard procedures were used to collect reservoir dust and to measure Der p 1 levels on the living room floor and child's bedroom floor and bedding. Der p 1 levels were analysed both as geometric mean $\mu\text{g/g}$ of fine dust and as $\mu\text{g/m}^2$. Questionnaires collected information about factors which might influence these levels, and an average relative humidity in the bed and on the bedroom floor was also measured.

Results Similar geometric mean levels of Der p 1 were found at each floor site – 25.5 $\mu\text{g/g}$ (95% CI: 22.8–28.5) in the living room and 26.4 $\mu\text{g/g}$ (95% CI: 23.7–29.3) on the child's bedroom floor. The geometric mean level of Der p 1 in the child's bed was 46.6 $\mu\text{g/g}$ (95% CI: 42.3–51.3). After controlling for possible confounders, geometric mean living room and bedroom floor Der p 1 levels were significantly higher in households with older carpet than households with no carpets or newer carpets, and higher in the autumn. Households with three or more children had higher levels of Der p 1 than households with fewer children. Bedding levels were significantly higher in beds with kapok or inner sprung mattresses, or wool underlays and at relative humidities above the mean (51%).

Conclusion The very high levels of house dust mite allergen (Der p 1) found in Wellington are likely to be due to a variety of life-style and climatic factors. However, the type and age of floor covering appears to be the single most important factor.

Keywords: house dust mites, Der p 1, floor covering, bedding, mattress, humidity, occupancy

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Introduction

New Zealand has a high prevalence of asthma with 26% of adults [1] and 28% of 13–14-year-olds [2] reporting wheezing in the last 12 months. There is evidence also that this prevalence is increasing [3,4]. Reasons for this high and increasing asthma prevalence are unknown, although it has long been believed that dust mite allergens play an

important role in both the development [5–8] and provocation [7,9,10] of asthma symptoms. The prevalence of positive skin-prick test sensitivity to *D. pteronyssinus* also suggests a major role for house dust mite allergy in the aetiology of asthma in this country. In Wellington (New Zealand), 76% of asthmatics, all of whom had a recent hospital admission, were skin-prick test positive to *D. pteronyssinus* [11]. This is the dominant mite in Wellington homes with 90% of mites in our study classified as this species [Pike, unpublished data, 1995].

New Zealand has a climate highly conducive to dust mite

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growth with monthly mean temperatures in Wellington ranging from 8.3°C in July (winter) to 16.7°C in February (summer) and high year round outdoor humidity (82% mean relative humidity [RH]) [12].

This study was initiated in response to these concerns and, perhaps surprisingly, is the first to measure domestic levels of Der p 1 in New Zealand and to examine factors that determine these levels.

Methods

The study took place in Wellington (New Zealand) between December 1993 and March 1995. It was undertaken as part of a case-control study which examined risk factors for asthma in 474 children aged 8–10. Cases and controls were randomly selected from the International Study of Asthma and Allergies in Children (ISAAC) [13]. This paper reports those factors found to influence Der p 1 concentrations in this population.

Reservoir dust was sampled once only from each household, from the living room floor, the child's bedroom floor and bedding of each child. The living room floor sample was taken from the centre of the room and the child's bedroom floor sample was taken from beside the head end of the child's bed, regardless of the floor covering at each site. Floor samples were collected from 1 m² of carpeted floor or 2 m² of uncarpeted floor. Bedding sampling included the mattress, underbedding and pillow as a composite sample. Each site was sampled for 1 minute using a Hitachi CV-2500 vacuum cleaner (1100 W) modified to collect dust in 25 µm pore-sized mesh bags inserted onto the vacuum head. Der p 1 levels were estimated using a monoclonal antibody ELISA [14]. The between batch coefficient of variation was 10.2%. When Der p 1 was undetectably low a value of 0.01 µg/g was assigned.

Interviewers collected questionnaire data on atopic diseases, social class of household, occupancy, bedding, soft toys, floor coverings, cleaning of bedding and floors, pets, dampness indicators and heating characteristics. Interviewer training and the presence of the survey coordinator at about 100 of the interviews ensured data was collected in a standardized way using questionnaires that had been extensively pretested.

Relative humidity was measured in the bed and on the child's bedroom floor using wax-coated 'starwood' tongue depressor sticks measuring 150 mm × 18 mm × 2 mm and weighing three grams. These were used to calculate a weighted average of relative humidity over approximately the previous 2 weeks. The gravimetric moisture content of the sticks at the time of recovery was determined by weighing, and this was equated to relative humidity via a known moisture content relation for the wood. [15] The results of analysis of sticks from the first 101 households

suggested that the response time of the wood used in the sticks was too long to give an accurate relative humidity reading in the time available and for this reason sticks subsequently used were scraped along one edge to increase their response rate. The analysis was restricted to measurements of relative humidity based on the 334 bed sticks and the 339 floor sticks with scraped edges and represent homes visited between mid-April 1994 and March 1995. Masking tape was used to tape the bed stick onto the mattress at about the child's waist level. Because of two instances where electric blankets melted the wax (> 70°C) causing damage to the mattress and electric blanket, bed sticks were subsequently placed under the child's pillow when an electric blanket was in use. The floor stick was taped 100 mm from an outside wall in a place free from furniture.

Data analysis was conducted separately for each site sampled using SAS. The data were approximately log-normally distributed so all analyses were performed using geometric means (with 95% confidence intervals). Geometric mean levels of Der p 1 were expressed both as µg/g and µg/m² for each floor site. However, we have adopted the recommendations of the first and second international workshops on mite allergens and asthma [5,16] and focused on reporting µg/g. The bed sampling method, devised to give a sample representative of likely exposure from combined bedding components, was standardized by collection time but not area, thus bed samples are expressed only as µg/g fine dust. One-way ANOVA on the log-transformed Der p 1 levels was used to calculate *P*-values in the univariate analyses. Multivariate analyses were performed using linear regression of the log-transformed Der p 1 levels. Correlations between continuous variables were also calculated on log-transformed Der p 1 levels using Pearson's correlation coefficient. A dampness score was estimated separately for the living room and bedroom based on the number of dampness indicators (condensation, dampness, mould) reported. Each indicator was scored as either 0 if absent or 1 if present, giving possible scores between 0 and 3 for each room.

The study was approved by the Central Regional Health Authority Ethics Committee.

Results

Of the 650 children selected for this study, 474 (73%) agreed to participate. However, four respondents refused all dust sampling and one refused the bedroom and bedding samples. One child's floor sample and two bed samples had insufficient dust for analysis. Dust was sampled from the remaining 470 living room floors, 468 bedroom floors and 467 beds. No differences were found in floor Der p 1 between 233 cases and 241 controls but bed levels were significantly lower for cases (*P* = 0.02). These results are to

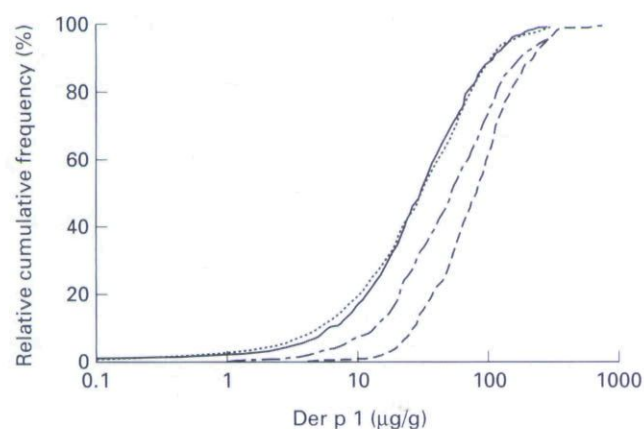


Fig. 1. Cumulative frequency of geometric mean concentrations of Der p 1 on living room floors, bedroom floors, and beds, and the highest concentration in each house. —, Highest value; ---, bedding; ·····, living room floor; —, bedroom.

be separately submitted for publication and cases and controls are combined in all further analysis presented here.

Figure 1 shows the distribution of the geometric mean concentrations of Der p 1 for each site over all assessments, and for the highest concentration in each house. All households had at least one site with a level $>2.0 \mu\text{g/g}$ (a suggested threshold for sensitization [5]), 99.1% of households included a level $>10.0 \mu\text{g/g}$ (a suggested threshold for provocation of asthma attacks [5]) and 35.7% of households had levels greater than $100.0 \mu\text{g/g}$ in at least one site. The geometric mean Der p 1 level for the highest concentration in each house was $73.2 \mu\text{g/g}$.

The correlation between Der p 1 expressed as $\mu\text{g/g}$ and $\mu\text{g/m}^2$ was 0.84 ($P=0.001$) for living room Der p 1 and 0.78 ($P=0.0001$) for bedroom floor Der p 1.

Table 1 shows the geometric mean levels of Der p 1 in the different sites expressed as $\mu\text{g/m}^2$ and $\mu\text{g/g}$. Similar levels were found on each floor site with significantly higher levels in the bedding. Geometric mean dust weights from floor sites were similar, but lower for bedding dust. There was a weak correlation between Der p 1 from different sites. The correlation between living room and bedroom floor $\mu\text{g/g}$ Der p 1 was 0.31 ($P=0.0001$) and between bedroom floor and bedding $\mu\text{g/g}$ Der p 1 was 0.17 ($P=0.0003$).

Floor

Table 2 shows significantly lower levels of Der p 1 on living room and bedroom floors without carpets or rugs compared with carpeted floors, and in carpets less than 1-year-old compared with carpets more than 1 year old. However, recency of vacuuming did not influence Der p 1 levels (not shown in tables). Significantly higher levels of Der p 1 were found in floor samples taken in the autumn months compared with other seasons. Indoor climate (not shown in tables) was less predictive of floor Der p 1 with non-significant trends toward increased Der p 1 with reported condensation, dampness and mould for each room (except for reported dampness in the bedroom), but there was no relationship between relative humidity on the bedroom floor and bedroom floor Der p 1 levels.

Increased occupancy measured as average household size (1–5 vs >5), number of people per room (<1 vs ≥ 1), and

Table 1. Geometric mean $\mu\text{g/g}$ and $\mu\text{g/m}^2$ Der p 1 (95% CI) and weight on the living room floor, bedroom floor and bedding

	<i>n</i>	Geometric mean	95% CI	Range	Quartile 1	Quartile 2	Quartile 3
Geometric mean $\mu\text{g/g}$							
Living room floor	470	25.5	(22.8–28.5)	(0.0–292.4)	13.1	29.7	60.7
Bedroom floor	468	26.4	(23.7–29.3)	(0.0–268.9)	14.5	29.8	58.6
Bedding	467	46.6	(42.3–51.3)	(0.7–721.0)	23.1	50.3	97.3
Geometric mean $\mu\text{g/m}^2$							
		95% CI	Range	Quartile 1	Quartile 2	Quartile 3	
Living room floor	470	28.4	(24.4–33.0)	(0.0–720.0)	14.0	38.0	83.5
Bedroom floor	468	24.8	(21.8–28.2)	(0.0–540.3)	10.9	29.1	64.1
Bedding	*	*	*	*	*	*	*
Geometric mean weight (g)							
		95% CI	Range	Quartile 1	Quartile 2	Quartile 3	
Living room floor	470	1.1	(1.1–1.2)	(0.0–13.0)	0.7	1.2	2.0
Bedroom floor	468	1.0	(0.9–1.1)	(0.0–12.9)	0.6	0.9	1.5
Bedding	467	0.5	(0.5–0.6)	(0.0–13.1)	0.3	0.6	1.0

* $\mu\text{g/m}^2$ not available for bedding.

Table 2. Univariate analysis showing factors significantly associated with geometric mean floor levels of $\mu\text{g/g}$ Der p 1 (95% CI)

	<i>n</i>	Geometric mean $\mu\text{g/g}$	95% CI	<i>P</i> -value
Living room floor	470			
Floor covering				
no carpet/rug	11	2.6	(0.6–10.8)	< 0.0001
carpet/rug	459	26.9	(24.2–29.9)	
Age of carpet				
no carpet/rug	11	2.6	(0.6–10.8)	
rugs only	23	8.2	(3.6–18.6)	0.006
carpet $\leq$ 1 year	16	8.3	(3.6–18.9)	
carpet > 1 year	416	30.4	(27.5–33.6)	
Season				0.0001
summer	67	25.0	(18.5–33.8)	
autumn	104	46.9	(36.3–60.6)	
winter	139	24.0	(20.2–28.6)	
spring	160	18.2	(15.00–22.0)	
Bedroom floor	468			
Floor covering				
no carpet/rug	14	3.9	(1.7–9.0)	< 0.0001
carpet/rug	452	28.1	(25.5–31.1)	
Age of carpet				
no carpet/rug	14	3.9	(1.7–9.0)	
rugs only	12	9.2	(3.8–22.8)	0.0001
carpet $\leq$ 1 year	14	19.4	(7.4–51.0)	
carpet > 1 year	426	29.6	(26.9–32.7)	
Season				0.0001
summer	65	20.9	(14.5–30.1)	
autumn	104	47.4	(39.5–56.9)	
winter	139	25.7	(21.7–30.5)	
spring	160	20.2	(17.0–24.1)	
Number of children				
< 3	206	23.2	(19.9–27.1)	0.03
3 +	262	29.2	(25.3–33.6)	

number of children in the household (1–2 vs ≥ 3) was consistently associated with higher concentrations of Der p 1. Table 2 shows the significant effect of the number of children in the household on $\mu\text{g/g}$ Der p 1 on bedroom floors. Although not shown in the tables, positive associations were found between most occupancy variables and Der p 1 expressed as $\mu\text{g/m}^2$. For example, levels of Der p 1 on the living room floor with 5 or more people in the household were $32.8 \mu\text{g/m}^2$ (compared with $23.44 \mu\text{g/m}^2$ with less than five people) ($P=0.03$), $36.1 \mu\text{g/m}^2$ with one or more people per room (compared with $26.1 \mu\text{g/m}^2$ with less than one person per room) ($P=0.06$), and $34.5 \mu\text{g/m}^2$ with three or more children in the household (compared

Table 3. Factors significantly associated with $\mu\text{g/g}$ floor Der p 1 after multivariate analyses

	<i>n</i>	Ratio of geometric mean $\mu\text{g/g}$	95% CI	<i>P</i> -value
Living room floor**	470			
Type and age of floor covering				
no carpet/rug	11	1.00*	—	0.0001
rugs only	23	3.7	(1.6–8.7)	
carpet $\leq$ 1 year	16	3.4	(1.4–8.3)	
carpet > 1 year	416	11.7	(3.8–35.9)	
Season sampled				0.0001
summer	67	1.00*	—	
autumn	104	1.9	(1.1–3.2)	
winter	139	1.0	(0.6–1.6)	
spring	160	0.8	(0.4–1.3)	
Bedroom floor***	468			
Number of children				
< 3	206	1.00*	—	0.02
3 or more	262	1.3	(0.8–1.9)	
Type and age of floor covering				
no carpet/rug	14	1.00*	—	0.0001
rugs only	12	2.9	(1.3–6.9)	
carpet $\leq$ 1 year	14	5.5	(2.5–12.4)	
carpet > 1 year	426	8.1	(4.2–15.6)	
Season sampled				0.0001
summer	65	1.00*	—	
autumn	104	2.3	(1.5–3.8)	
winter	139	1.3	(0.8–2.0)	
spring	160	0.9	(0.6–1.5)	

*Reference category.

**Adjusted for all variables shown in table plus number of children and living-room dampness score.

***Adjusted for all variables shown in table plus bedroom dampness score.

with $22.1 \mu\text{g/m}^2$ with fewer children) ($P=0.004$). Bedroom floor levels of Der p 1/ $\mu\text{g/m}^2$ were also significantly higher where there were five or more people in the household ($29.8 \mu\text{g/m}^2$ compared with $21.0 \mu\text{g/m}^2$ with less than five people) ($P=0.01$), 1 or more people per room ($31.2 \mu\text{g/m}^2$ compared with $22.9 \mu\text{g/m}^2$ with fewer people per room) ($P=0.04$) and three or more children in the household ($30.0 \mu\text{g/m}^2$ compared with $19.4 \mu\text{g/m}^2$ with fewer children) ($P=0.0009$). For the living room and bedroom floors, dust weights were also significantly higher with higher occupancy measures. No significant associations were found between Der p 1 levels on living room floors and the presence or absence of cats, dogs or birds. On the bedroom

Table 4. Univariate analysis showing factors significantly associated with geometric mean $\mu\text{g/g}$ bed Der p 1 (95% CI)

	<i>n</i>	Geometric mean $\mu\text{g/g}$	95% CI	<i>P</i> -value
	467			
Type of mattress				
kapok	11	70.9	(37.3–134.6)	0.005
inner sprung	321	50.2	(44.8–56.3)	
foam	115	39.3	(32.4–47.6)	
cotton	4	38.4	(10.3–143.1)	
waterbed	12	19.6	(9.6–39.8)	
Type of underbedding				
wool underlay	93	75.6	(61.5–92.9)	<0.0001
no wool underlay	374	41.3	(37.2–45.9)	
foam squab	28	31.9	(22.5–45.1)	0.05
no foam squab	439	47.7	(43.2–52.7)	
Plastic/rubber sheet				
plastic sheet	44	34.2	(25.8–45.3)	0.04
no plastic/rubber sheet	423	48.1	(43.5–53.3)	
Washing of underbedding				
not washed in last 12 months	215	47.5	(41.5–54.4)	0.0003
washed < 3 times	125	59.3	(49.2–71.4)	
washed 3–6 times	68	41.9	(32.5–54.1)	
washed > 6 times	52	28.4	(20.9–38.6)	
Floor covering				
no carpet/rug	15	19.9	(8.9–44.7)	0.001
carpet/rug	451	48.1	(43.8–52.9)	
Age of carpet				
no carpet/rug	15	19.9	(8.9–44.7)	0.009
rugs only	12	44.1	(30.5–63.8)	
carpet $\leq$ 1 year	14	66.6	(47.2–93.9)	
carpet > 1 year	424	47.7	(43.2–52.7)	
Condensation in bedroom				
yes	335	49.5	(44.2–55.4)	0.05
no	132	40.0	(33.4–47.9)	
Dampness in bedroom				
yes	63	60.0	(46.8–76.9)	0.04
no	404	44.8	(40.4–48.7)	
Relative humidity on mattress				
$\leq$ mean (51%)	188	41.3	(35.7–47.7)	0.03
> mean (51%)	146	52.8	(44.9–62.3)	

floor, significantly lower levels were found where cats entered bedrooms (23.13 $\mu\text{g/g}$ compared to 29.15 $\mu\text{g/g}$ where cats did not go in bedrooms) ($P=0.03$), but levels were not significantly affected by the presence or absence of dogs or birds. Type of heating also did not significantly affect Der p 1 levels at any floor site.

For the living room floor, number of children, the living room dampness score, type and age of floor covering and

season were included in a multivariate model. The presence of floor covering and age of the carpet, and season remained significantly related to $\mu\text{g/g}$ of Der p 1 on the living room floor (Table 3). Number of children ($P=0.10$) and living room dampness ($P=0.33$) became non-significant. The addition of a social class variable (based on occupation) to the model did not alter the outcome.

For the bedroom floor, linear regression modelling used

a model which included number of children, the bedroom dampness score, type and age of floor covering and season. Statistically significant differences were found with higher levels of Der p 1 associated with the presence and age of floor covering, season and the number of children in the household (Table 3). Again social class was not a confounding variable.

Additional univariate analysis showed that respondents with carpets more than 1-year-old reported more dampness indicators in the living rooms ($P=0.04$) and bedrooms ($P<0.0001$) than respondents with no or newer carpets. For example in the living room, 60% of respondents with no or newer carpets reported condensation, dampness or mould, compared with 74% of people with carpets more than one year old. 57% of respondents with no or new carpet reported condensation, dampness or mould in the bedroom, compared with 76% of people with older carpets. Living room ($P=0.01$) and bedroom ($P=0.001$) dampness scores were also positively associated with the number of children in the household. 77% of households that reported condensation, dampness and mould in the living room or bedroom had 3 or more children. (Not shown in tables.) The multivariate analysis suggests that number of children is more important than dampness as a predictor of Der p 1 levels.

Bed

Table 4 shows factors significantly associated with bed Der p 1 in the univariate analysis. The type of mattress significantly affected bed Der p 1. Kapok (a natural product similar to cotton) and inner sprung mattresses had relatively high Der p 1 and waterbeds low Der p 1. The presence of a wool underlay was significantly associated with higher Der p 1 while a layer of foam rubber on top of the mattress and the use of plastic or rubber sheets were associated with lower Der p 1. Significantly higher levels of Der p 1 were found in beds where underbedding had not been washed or had been washed less than three times in the last 12 months compared with underbedding that is more frequently washed. Carpets or rugs on the bedroom floor, particularly if the carpet was more than 1 year old, were also associated with significantly higher bed Der p 1. All dampness measures were positively correlated with bed Der p 1 and this was significant for reported condensation, reported dampness and relative humidity on the mattress. However, there was no seasonal variation in bed Der p 1.

Higher bed Der p 1 levels were also found associated with sheepskins (64.2 $\mu\text{g/g}$ compared with 46.1 $\mu\text{g/g}$ where there was no sheepskin) but perhaps because of the small number of children in this age group who use sheepskins ($n=16$) this difference did not reach significance. Airing of bedding more than six times in the last 6 months was associated with lower Der p 1 (30.1 $\mu\text{g/g}$ compared with 47.1 $\mu\text{g/g}$ in

Table 5. Factors significantly associated with $\mu\text{g/g}$ bed Der p 1 (95% CI) after multivariate analysis

	<i>n</i>	Ratio of geometric mean $\mu\text{g/g}^{***}$	95% CI	<i>P</i> -value
Bedding	330**			
Type of mattress				
foam	77	1.00*	—	0.0009
waterbed	9	0.4	(0.1–1.9)	
cotton	2	1.0	(0.0–26.3)	
inner sprung	235	1.4	(0.6–3.3)	
kapok	7	1.6	(0.3–9.1)	
Wool underlay				
no wool underlay	258	1.00*	—	0.0001
wool underlay	72	1.9	(0.6–5.5)	
Relative humidity				
< = mean (51%)	184	1.00*	—	0.005
> mean (51%)	146	1.4	(0.6–3.0)	

* Reference category.

** Reduced *n* because humidity stick data not available for all respondents.

*** Adjusted for all variables shown in table plus whether sheepskin, whether plastic/rubber cover, frequency of washing underbedding and frequency of airing underbedding.

bedding not aired in the last 12 months) ($P=0.06$). Frequent airing of mattresses and pillows was also non-significantly associated with lower concentrations of Der p 1. The age of the mattress, the presence of an electric blanket on the bed, the number of beds in the room, the number of soft toys, or the presence or absence of cats, dogs or birds in the bedroom did not influence bed Der p 1. Type of heating also had no effect on bed Der p 1. (Not shown in tables.)

Bed Der p 1 levels were not significantly affected by any of the occupancy variables although there was a tendency for higher bed Der p 1 levels in less crowded and smaller households and families. Higher geometric mean weights of bed dust were also found to be significantly associated with less crowded households.

Table 5 shows only those variables that remained significant in the multivariate analysis. These were mattress type, presence of a wool underlay, and relative humidity. The inclusion of relative humidity in the model meant it was restricted to those respondents for whom relative humidity data was available ($n=330$). Sheepskins, plastic covers on the mattress, frequency of washing or airing the underbedding and floor covering were not significant, although there were trends towards higher Der p 1 levels associated with the presence of sheepskins (ratio: 1.23) and associated

with rugs only on the bedroom floor (ratio: 2.64), carpet less than one-year-old (ratio: 2.61) and carpet more than 1-year-old (ratio: 2.44) compared to uncovered floors. The separate addition of variables to the model for the age of the mattress, bedroom dampness measures, number of children and social class (based on occupation) did not explain any additional variation in Der p 1 levels in the bed.

When the variable for washing frequency was stratified by relative humidity, washing of bedding was associated with lower Der p 1 levels only when relative humidity was below the mean (51% RH) ($P=0.05$). Further univariate analysis of factors associated with bed Der p 1 showed significant differences in humidity depending on type of mattress ($P=0.0001$): 71% of kapok, 62% of foam/rubber, 50% of cotton, 38% of inner sprung mattresses and 30% of waterbeds were associated with above average humidities.

Discussion

This study found very high Der p 1 levels on floors and in beds in Wellington homes. A major role for this allergen in the causation of asthma has been convincingly argued [17]. Thus it is important to determine the factors responsible for these high Der p 1 levels so that environments can be modified to reduce both primary sensitization in infancy and the provocation of symptoms in those already sensitized.

Carpets

Carpets and rugs have been consistently associated with higher Der p 1 in both homes [18] and public places [19]. Der p 1 was much higher on carpeted compared to uncovered floors and in older compared with newer carpets. Although older carpets were found in damper environments, dampness did not explain the higher levels found in older carpets. Carpets or rugs on floors were also associated with more than twice the level of bed Der p 1 compared with levels in beds beside uncovered floors. This suggests that removal or treatment of carpets would be beneficial in reducing Der p 1 exposure directly from carpets and indirectly from bedding.

Occupancy

Household size, number of children and concentration of people were factors influencing levels of floor Der p 1, with this influence increasing when Der p 1 was expressed as $\mu\text{g}/\text{m}^2$. Higher occupancy was also significantly associated with the presence of more dust. Of all the occupancy variables, number of children had the greatest influence on Der p 1. Similar associations with occupancy and floor Der p 1 have been found by van Strien [18] (expressed as $\mu\text{g}/\text{g}$ and $\mu\text{g}/\text{m}^2$)

and Chan-Yeung [20] ($\mu\text{g}/\text{g}$ only reported). In contrast, Kuehr [21] found a significant negative association between Der p 1, measured as $\mu\text{g}/\text{g}$ and persons per m^2 . We found increased dampness scores in homes with greater numbers of children, but after controlling for confounders the number of children showed a more consistent association with Der p 1 than dampness. The reasons for this are unclear but it is possible that children shed more skin scales during play on the floor resulting in a greater abundance of skin scales as a food source for mites. Although previous reports from Denmark [22–23] have suggested that mite populations are not limited by food supply it is questionable whether data from Denmark, with low mite levels, can be extrapolated to New Zealand where levels are many times greater. In New Zealand, food supply may be more important than humidity in limiting mite population growth.

Indoor and outdoor climate

We did not find a strong relationship between humidity and floor Der p 1 levels. A study in Manchester, England, where relative humidities are also high all year round and similar to those in Wellington, also did not find a correlation between Der p 1 and relative humidity [24]. This is in contrast to laboratory [12] and epidemiological [18, 25, 26] studies in countries with cold dry winters that have found that dust mite survival is related to humidity. It is likely therefore that we did not find a positive correlation between Der p 1 and humidity because humidity is constantly above the threshold needed for dust mite survival in New Zealand.

Epidemiological studies have often ignored the role that temperature plays in dust mite survival. For example, for a given relative humidity of 55%, at 15°C dust mites will gain water but at 25°C they will lose water [12]. We did not collect data on temperature but central heating is uncommon in New Zealand and homes often have areas, particularly bedrooms, that are poorly heated resulting in lower indoor temperatures than in European or North American homes where central heating is more common.

Consistent with our finding, significantly higher levels of Der p 1 in autumn have been previously described [24, 27, 28] and these have been associated with increasing indoor [24] and outdoor humidity [27, 28]. Since we found no seasonal variation in our measurements of indoor relative humidity on bedroom floors it is difficult to explain our finding of higher floor Der p 1 in the autumn in terms of a change in relative humidity but falling temperatures in autumn may have contributed to our finding. There is little seasonal fluctuation in mean outdoor relative humidity in Wellington (summer: 79.8%, autumn: 82.7%, winter: 85.6%, spring: 79.9%).

In contrast to floor Der p 1, all humidity measures were

positively correlated with bed Der p 1 with this effect increasing after controlling for confounding by number of children and social class. This suggests that humidity is the factor limiting mite growth in beds either because food supply is plentiful, or because higher bed temperatures result in lower humidity environments than floors. Since live mite counts were not performed in this study, we cannot determine whether the higher levels of Der p 1 in beds reflect greater colonization, or simply greater accumulation of allergen because of different cleaning practices in beds from those on floors. Interestingly, the lack of seasonal variation in bed allergen levels suggests a more stable, insulated microenvironment compared with floors.

Bedding

Mattress type was significantly related to Der p 1 levels. Although there were differences in humidity between mattress types, humidity did not explain differences in Der p 1 levels between mattresses. Two other New Zealand studies have identified differences, consistent with this study, depending on mattress type. High numbers of mites have been found on kapok and inner sprung compared with foam rubber mattresses [29] while house dust mite sensitivity has been significantly associated with the use of inner sprung mattresses [30]. A study from Denmark also found higher levels of allergen associated with inner sprung mattresses [31]. Because large numbers of children in our study use these mattresses ($n=321$) public health interventions that aim to reduce exposure to inner sprung mattresses are important.

Wool underlays, which are similar to sheepskins in that they have a long pile and are made of wool, were found to be a major risk factor contributing to high levels of Der p 1. They were not associated with greater bed humidity, suggesting that some other characteristic of wool underlays, such as the long pile, may explain why they are a preferred environment for dust mites. Although Der p 1 levels in wool underlays have not been previously measured, levels in sheepskins have been found to be significantly higher than in other infant bedding [32].

Washing and airing

After controlling for confounders, airing of bedding was not significantly related to Der p 1 and washing of bedding was associated with lower levels of Der p 1 in low humidity environments only. Washing may be ineffective at high humidities because in these conditions a rapid increase to pre-wash allergen levels recurs. The effect of washing may have been diluted if frequency of washing had been overreported.

In conclusion, this study has demonstrated high levels of

house dust mite allergen throughout Wellington homes and identified factors associated with these levels. The bed is a major source of Der p 1 exposure and controlling levels in the bed is important but to be effective the total home environment may need to be modified. Strategies should be multifaceted and include: avoidance of high risk mattress types and wool underlays, reductions in bed humidity, the washing of bedding and, perhaps the single most important strategy, the removal of carpets. To reduce levels of Der p 1 below that of sensitization ($2 \mu\text{g/g}$) or provocation ($10 \mu\text{g/g}$) will be a major challenge for the inhabitants, the building industry and for health professionals in New Zealand.

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