

Residential characteristics predict changes in Der p 1, Fel d 1 and ergosterol but not fungi over time

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Summary

Background Allergen and fungal exposures are important risk factors for asthma. We conducted a longitudinal analysis of allergen levels in Melbourne homes between 1996 and 1998 to examine the effects of changing residential characteristics on allergen and fungal levels. We also examined the changes in levels of indoor allergens.

Methods The subjects were participants in the European Community Respiratory Health Survey (ECRHS) in Melbourne. In 1996, 485 subjects participated in a follow-up study, which involved both home and laboratory visits. Dust and air samples were collected from participants' bedrooms and a validated residential questionnaire was administered. In 1998, 360 participants underwent further follow-up. House dust mite (Der p 1) and cat allergens (Fel d 1) and ergosterol were measured in dust.

Results We observed moderate within home correlations between 1996 and 1998 in floor Der p 1 (intraclass correlation ICC = 0.48), bed Der p 1 (ICC = 0.61), Fel d 1 (κ = 0.53) and ergosterol (ICC = 0.28) levels. We found that the floor Der p 1 levels decreased from 1996 to 1998 in the homes of participants who moved to an attached home, moved their bedrooms to the first floor, removed fitted carpet or central heating. Replacing or vacuuming the mattress more than twice per year reduced levels of Der p 1 in the bed. Ergosterol levels were reduced by removing visible mould and fitted carpet.

Conclusions These findings provide evidence to support current advice with regard to allergen avoidance in patients with dust mite and fungal allergies.

Keywords allergens, asthma, fungi, house dust mite, residential characteristics

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Introduction

Exposure to house dust mite allergen (Der p 1), cat allergen (Fel d 1) and fungi are important risk factors for asthma. Avoidance of these allergens has been shown to reduce bronchial hyperreactivity and asthma symptoms [1]. The concentration of house dust mite (HDM) allergen in Australian homes is amongst the highest in the world and may be a reason for the high prevalence of asthma in this country [2, 3]. Many studies have investigated the relationship between residential characteristics and allergen levels in homes around the world. Some common factors have emerged that have been repeatedly shown to influence

HDM allergen levels such as relative humidity, frequency of ventilation and the presence of fitted carpets. In our cross sectional study conducted in 1996, we identified older, wooden floored houses, woollen carpets, older mattresses, visible dampness and mould as significant residential predictors of high Der p 1 levels [2]. We also observed high indoor fungal levels associated with infrequent ventilation or vacuuming, presence of pets, visible mould and old carpets [4].

However it is still not known to what extent changing residential characteristics impacts on allergen levels. Nor whether advising patients with house dust mite sensitivity to remove all carpets actually reduces Der p 1 exposure. Therefore an understanding of the effects of changing residential characteristics upon allergen and fungal levels is an essential step in designing rational avoidance measures and making clinical recommendations for people with allergic asthma.

The aim of the present study was to conduct a longitudinal analysis of the effects of changing residential characteristics

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on allergen and fungal levels. We also examined the changes in levels of indoor allergens.

Methods

Subjects

The subjects were participants in the European Community Respiratory Health Survey (ECRHS) in Melbourne, Australia. The two-phase sampling procedure has been described in detail elsewhere [5]. However briefly stage 1 was started in 1992 with a short screening survey sent to 4500 adults aged between 20 and 45 years from the south eastern suburbs of Melbourne. Respondents to this survey were then invited to participate in stage 2, which involved attending our lung function laboratory at the Alfred Hospital to undergo more extensive respiratory testing. A total of 757 attended the laboratory between 1993 and 1994. The Melbourne centre then followed up these stage 2 participants for an Environmental Causes of Asthma Study started in 1996. All participants in the ECRHS stage 2 were invited to participate. Participants and their homes were investigated in 1996 and then again 1998. In 1996, 485 people participated in both the laboratory visit and the home visit. In 1998, 360 of the original 485 participants took part in both the follow-up laboratory and home visits. The study was approved by the Ethics Committee at the Alfred Hospital in Melbourne, Australia. Written informed consent was obtained from all participants.

Questionnaires and laboratory procedures

The questionnaires and laboratory procedures used in this study were identical in both years and the exact methods used have been described previously [2, 4]. Briefly, in 1996 and again in 1998 participants were visited once at home in random order. A validated interviewer-administered questionnaire was used to collect information about residential characteristics [6]. During this visit, floor dust, bed dust and air samples were collected from participants' bedrooms. Dust samples were assayed for dust mite allergen (Der p 1) and cat allergen (Fel d 1), with standard immunoassays [2]. If sufficient quantities of dust remained after assaying for Der p 1 and Fel d 1, then they were analysed for ergosterol a marker of cumulative fungal biomass, by high-performance liquid chromatography (HPLC) [7]. The identity and abundance of viable fungal propagules suspended in the air at the time of sampling were estimated using a two stage Andersen sampler (Graseby/Andersen, Atlanta, GA, USA) as described previously [4]. The resulting colonies of fungi were identified on the basis of colony and spore morphology and expressed as colony forming units per cubic meter of air (CFU/m³).

Of the 360 participants in this study, we had Der p 1 results for floor dust from 355 homes, bed dust results from 356 homes, Fel d 1 in floor dust from 353 homes and ergosterol from 322 homes. Viable fungal propagule counts were available from 359 homes. Data was not available for all participants due to an insufficient dust sample being collected from the subject's bedroom or insufficient dust remaining for measurement of ergosterol after the assays for Der p 1 and Fel d 1 were completed.

Statistical analysis

The statistical package Stata (Version 6.0; STATA Corporation, TX, USA) was used to analyse the data. The distributions of all the allergen and fungal levels were positively skewed. Log transformation normalized the distributions of total fungal propagules, *Cladosporium*, other fungal propagules, ergosterol and Der p 1 levels. Intra-class (within home) correlations were used to assess agreement beyond chance between levels in 1996 and 1998 of total fungal propagules, *Cladosporium*, other fungal propagules, ergosterol and Der p 1. Cohen's κ was used for Fel d 1, *Penicillium*, *Aspergillus*, *Alternaria* and *Epicoccum*, which had to be analysed as categorical variables. Since the distribution could not be normalized, Fel d 1 levels were categorized by using the cut off points suggested as threshold levels for sensitization and symptoms of asthma respectively i.e.: 2 and 8 $\mu\text{g/g}$ of dust [8]. *Penicillium*, *Aspergillus*, *Alternaria* and *Epicoccum* were simply defined as present or absent. Changes from 1996 to 1998 in the proportions of subjects with specific residential characteristics were compared using McNemar's χ^2 test.

Changes from 1996 to 1998 in allergen levels were compared between two groups of subjects – those who changed a residential characteristic from 1996 to 1998 versus those who did not. This produced two comparisons, the first being of those who obtained a new characteristic (e.g. laying carpet) versus those never having the characteristic (never having carpet), and the second being those who removed a characteristic (removing carpet) compared to those always in possession of the characteristic (always having carpet). Comparisons between groups were obtained by multiple linear regression of the differences in the logarithm of allergen levels between 1996 and 1998 on residential characteristics.

Those residential characteristics found to be significant at the univariate level were then included in the multivariate models to identify the significant independent explanatory variables for the change in allergen and fungal levels. Summary statistics are presented for each group in the form of the geometric mean of the proportional changes in allergen levels from 1996 to 1998. All analyses adjusted for season of measurement and relative humidity in both years, the additional variables for which adjustments were made in each analysis are listed in the figures. The comparison between groups is presented as the ratio of these adjusted geometric mean changes together with 95% confidence intervals (CI) and *P*-values. Relative humidity was defined as the ratio of the measured partial vapour pressure of water to the saturation vapour pressure at that temperature. Type of house was categorised into seven options: detached/freestanding house, semi-detached house, terraced or town house, unit, apartment or flat, studio apartment and other. These last six options were then grouped into the attached house category.

To assess whether individual or sets of data points markedly affected the results, all analyses were repeated with a more robust regression (using the *rreg* command in Stata Version 6). This procedure initially fits a linear regression and then downweights outlying data points in an iterative fashion until the results are stable. As these analyses produced results similar to the linear regressions, only the linear regression results are presented, with comments concerning the few discrepancies included where appropriate.

Results

Correlations of allergen and fungal levels between 1996 and 1998

The distributions of allergen levels in 1996 and 1998 are listed in Table 1. The geometric mean level of Der p 1 in floor dust increased from 17.5 in 1996 to 26.9 µg/g of dust in 1998 ($t = 5.92$, $P < 0.0001$). The levels in 1996 were positively correlated with levels in the same homes in 1998 (Intraclass correlation [ICC] = 0.48, $P < 0.001$). The geometric mean levels of Der p 1 in bed dust were 21.0 and 25.1 µg/g of dust in 1996 and 1998, respectively ($t = 2.95$, $P < 0.0001$) and had a similar strong positive correlation (ICC = 0.61, $P < 0.001$). The median levels of Fel d 1 were 1.6 and 0.5 µg/g of dust in 1996 and 1998 respectively ($z = 5.2$, $P < 0.0001$) and there was moderate agreement between levels in 1996 and 1998 ($\kappa = 0.53$, $P < 0.001$). The geometric mean levels of total fungal propagules ($t = 8.58$, $P < 0.0001$), *Cladosporium* ($t = 7.17$, $P < 0.0001$) and the combined category of other fungi ($t = 9.22$, $P < 0.0001$) all decreased from 1996 to 1998. There were negligible correlations between 1996 and 1998 levels for all fungal groups. The geometric mean levels of ergosterol were lower in 1998 than in 1996 ($t = 5.94$, $P < 0.0001$) and were positively correlated (ICC = 0.28, $P = 0.002$). Also presented in Table 1 are the correlation coefficients matched for season of measurement. As shown this does not substantially alter the resulting correlations.

Residential predictors of change in allergen levels

The proportions of subjects' homes with selected residential characteristics in 1996 and 1998 are listed in Table 2. The proportion of subjects with central heating, an extractor fan over the cook top, air conditioning, ceiling fans, vacuuming their mattress and using a solid fuel fire increased significantly from 1996 to 1998. Conversely, the proportion of subjects with observed mould and vertical blinds decreased significantly by 1998.

Residential predictors of change in floor Der p 1 levels

The residential characteristics that were significant predictors of change in floor Der p 1 levels are presented in Fig. 1. The floor Der p 1 levels for participants with freestanding homes

increased 67% from 1996 to 1998 (adjusted ratio of geometric means was 1.67, 95%CI 1.44–1.93). For participants who moved to an attached home, Der p 1 levels decreased 72% (adjusted ratio of geometric means was 0.28, 95%CI 0.15–0.52), which was a significant difference in Der p 1 exposure compared to those who remained in a freestanding home ($P < 0.0001$). This model explained 27.8% of the variation in floor Der p 1 levels. Participants who installed central heating had a 21% decrease in their mean floor Der p 1 levels from 1996 to 1998. On the other hand, those participants who never had central heating experienced a 88% increase in Der p 1 exposure, which was a statistically significant difference ($P = 0.001$). Conversely participants who removed central heating had a 29% decrease in Der p 1 floor levels, which was significantly different to the 55% increase experienced by those who retained central heating ($P = 0.02$). This model explained 26% of the variation in floor Der p 1 levels. For participants who moved their bedrooms to the first floor, mean Der p 1 levels decreased 85% from 1996 to 1998, which was significantly different compared to the 81% increase experienced by those bedrooms remained on the ground floor in both years ($P < 0.0001$). This model explained 26.6% of the variation in floor Der p 1 levels.

The floor Der p 1 levels in houses that never had carpet increased 88% from 1996 to 1998. This was highly significantly different from the 477% increase in Der p 1 levels in houses where carpet was fitted by 1998 ($P = 0.002$). Conversely in the homes of participants who removed carpet, the floor Der p 1 levels decreased 44% from 1996 to 1998, which was significantly different from the 43% increase in Der p 1 levels observed in the homes of participants who retained carpet in both years ($P = 0.006$). This model explained 22.7% of the variation in floor Der p 1 levels. When robust regression was used the comparison between moving to a concrete slab and remaining on a wooden floor with stumps became significant ($P = 0.03$).

Residential predictors of change in bed Der p 1 levels

The residential characteristics that were significant predictors of change in bed Der p 1 levels are presented in Fig. 2. Those who reported only in 1996 that they had a mattress older than 5 years (i.e. replaced their mattress by 1998) had a 21% decrease in mean bed Der p 1 levels. This was significantly

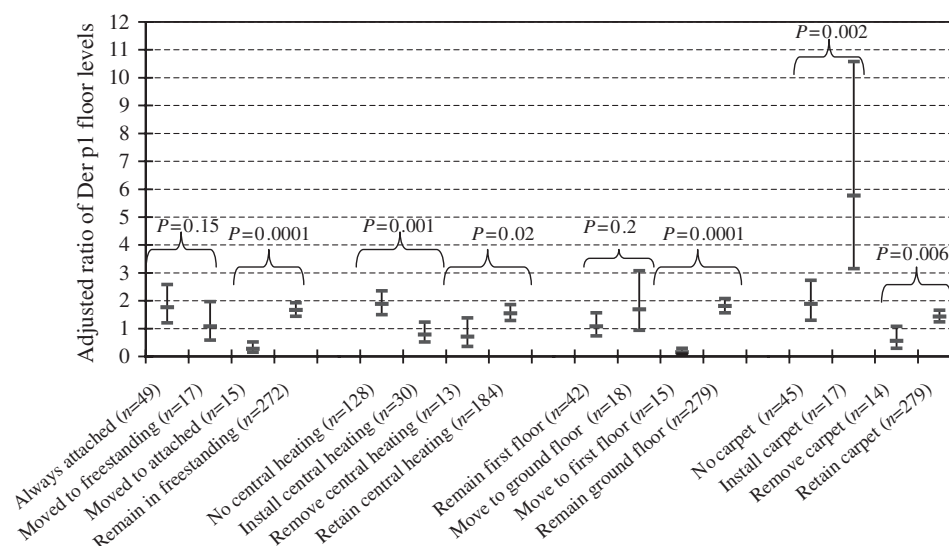
Table 1. Descriptive statistics and intra-class (within home) correlation co-efficients for allergen levels, ergosterol and fungal propagules between 1996 and 1998

Allergen	<i>n</i>	1996	1998	Correlation (95% CI)	<i>P</i>	<i>n</i>	Correlation (95% CI)‡	<i>P</i>
Der p 1 floor (µg/g) (GM, IQR)	355	17.5 (6.0–51.5)	26.94 (11.2–69.1)	0.48 (0.39–0.55)*	<0.001	118	0.38 (0.22–0.53)*	<0.001
Der p 1 bed (µg/g) (GM, IQR)	356	20.98 (7.8–47.4)	25.05 (9.70–61.8)	0.61 (0.54–0.67)*	<0.001	118	0.68 (0.57–0.77)*	<0.001
Fel d 1 floor (µg/g) (Median, IQR)	353	1.6 (0.4–24.8)	0.5 (0.1–8.5)	0.53†	<0.001	117	0.54†	<0.001
Ergosterol (µg/g) (GM, IQR)	322	3.95 (1.9–7.85)	2.39 (0–5.59)	0.28 (0.17–0.37)*	0.002	111	0.27 (0.09–0.43)*	0.002
Total fungi (CFU/m³) (GM, IQR)	359	543.6 (368–811)	292 (184–589)	–0.01 (–0.2 to –0.005)*	0.97	118	–0.09 (–0.27 to –0.09)*	0.84
<i>Cladosporium</i> (CFU/m³) (GM, IQR)	359	97.5 (37–329)	33 (37–146)	–0.04 (–0.14 to –0.067)*	0.75	118	–0.003 (–0.18 to –0.18)*	0.51
<i>Penicillium</i> (CFU/m³) (Median, IQR)	359	73.26 (37–110)	37 (0–110)	0.0159†	0.62	118	0.03†	0.59
<i>Aspergillus</i> (CFU/m³) (Median, IQR)	359	0 (0–1)	0 (0–1)	0.0215†	0.68	118	–0.006†	0.94
<i>Alternaria</i> (CFU/m³) (Median, IQR)	359	0 (0–0)	0 (0–1)	0.0194†	0.7	118	–0.02†	0.76
<i>Epilobium</i> (CFU/m³) (Median, IQR)	359	0 (0–1)	0 (0–1)	–0.013†	0.77	118	–0.01†	0.90
Other fungi (CFU/m³) (GM, IQR)	356	197 (146–329)	70 (37–220)	–0.02 (–0.1 to –0.08)*	0.66	117	–0.16 (–0.33 to –0.02)*	0.96

*Intra-class correlation. †Kappa (κ). ‡Matched for season sampled ($n = 118$). GM = geometric mean, IQR = inter quartile (25–75%) range.

Table 2. Proportion (%) of subjects with selected residential characteristics in 1996 and 1998

Residential characteristic		1996	1998	P-value
Type of house	Freestanding	81.6	81.7	0.72
Base of bedroom	Wood	77.5	76.4	0.57
Level of bedroom	Ground	82.8	83.8	0.60
Presence of central heating		56.1	60.8	0.001
Observed damp patches		25.8	24.2	0.54
Observed mould		37.3	29.4	0.002
Extractor fan over cook-top		80.3	84.4	0.007
Heavy window drapes		58.6	58.9	0.90
Venetian blinds		15.3	18.1	0.10
Fitted carpet		82.8	83.3	0.72
Type of carpet	Wool	19.2	19.0	0.88
Age of carpet (years)	> 1	95.0	94.7	0.54
Age of mattress	> 5	64.1	64.3	0.99
Quilt on bed		93.1	93.6	0.64
Blankets on bed		23.6	20.3	0.10
Air conditioning		33.6	40.3	0.0005
Vacuumed Mattress in last 12 months		22.2	27.2	0.04
Ceiling fan present		16.1	18.3	0.03
Vertical blinds present		7.5	5.0	0.05
Sleep with windows open		35.8	35.6	0.90
Windows open at time of sampling		47.2	45.3	0.99
Vacuum of bedroom prior to sampling	> 1 week ago	18.9	20.4	0.51
Fire used in the house in last 12 months		32.2	37.2	0.01
Frequency of bedroom airing	< once per week	42.2	45.6	0.22
Cats		31.9	29.7	0.07
Number of cats	> 1	19.1	25.2	0.29
Cats allowed inside		94.7	90.7	0.10
Cats allowed in bedroom		67.5	73.8	0.23
Cats in the house in the last 12 months		5.7	6.3	0.32
Dogs		40.0	41.9	0.31

**Fig. 1.** Adjusted ratio of floor Der p 1 levels in 1998 to 1996 for selected residential characteristics. (Adjusted for season sampled, relative humidity, type of house, base construction of bedroom, level of bedroom, fitted carpet and central heating.)

different to the 25% increase among those who reported they had a mattress older than 5 years in both 1996 and 1998 ($P = 0.007$). This model explained 9.9% of the variation in bed Der p 1 levels. Those participants who reported they had vacuumed their mattress in the last 12 months in 1998 only

had a 15% decrease in bed Der p 1 levels. This was significantly different from the 30% increase found for those who reported they never vacuumed their mattress ($P = 0.02$). This model explained 8.5% of the variation in bed Der p 1 levels. However this comparison was no longer significant

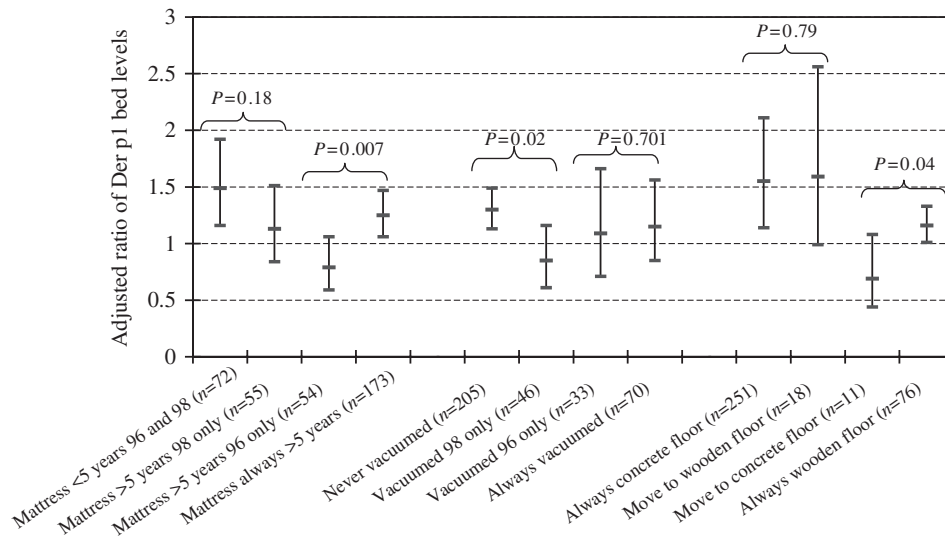


Fig. 2. Adjusted ratio of Bed Der p 1 levels in 1998 to 1996 for selected residential characteristics. (Adjusted for season sampled, relative humidity, type of house, base construction of bedroom, extractor fan over cook-top, age of mattress and vacuumed mattress in the last 12 months.)

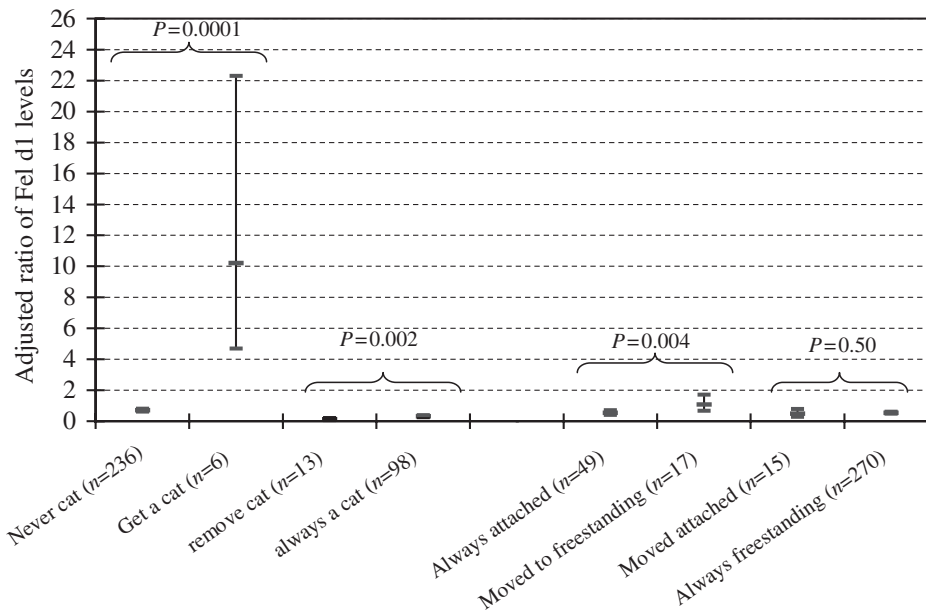


Fig. 3. Adjusted ratio of Fel d 1 levels in 1998 to 1996 for selected residential characteristics. (Adjusted for season sampled, relative humidity, type of house and the presence of cats.)

when robust regression was used ($P = 0.173$). Interestingly, the type of floor construction also had an effect on bed Der p 1 levels. Participants who remained in a home with stumps and wooden flooring, had a 16% increase in mean bed Der p 1 levels from 1996 to 1998. Participants who moved to a home with a concrete slab floor had a 31% decrease in bed Der p 1 levels, which was significantly different to those who remained on stumps and wooden flooring ($P = 0.04$). This model explained 8.1% of the variation in bed Der p 1 levels. When robust regression was used we also found the comparison between those who moved to a freestanding house and those who remained in an attached house became significant ($P = 0.01$). Similarly the comparison between those who moved to an attached home and those

who remained in a freestanding home also became significant ($P = 0.03$).

Residential predictors of change in Fel d 1 levels

The residential characteristics that were significant predictors of changes in Fel d 1 levels in house dust are presented in Fig. 3. Those participants who acquired a cat had a 925% increase in their mean floor Fel d 1 levels. This was significantly more than participants who never had a cat, whose Fel d 1 levels decreased 29% ($P < 0.0001$). Similarly those who removed a cat had an 88% reduction in Fel d 1 levels, which was significantly different from those who always had a cat, whose levels decreased 68% ($P = 0.002$).

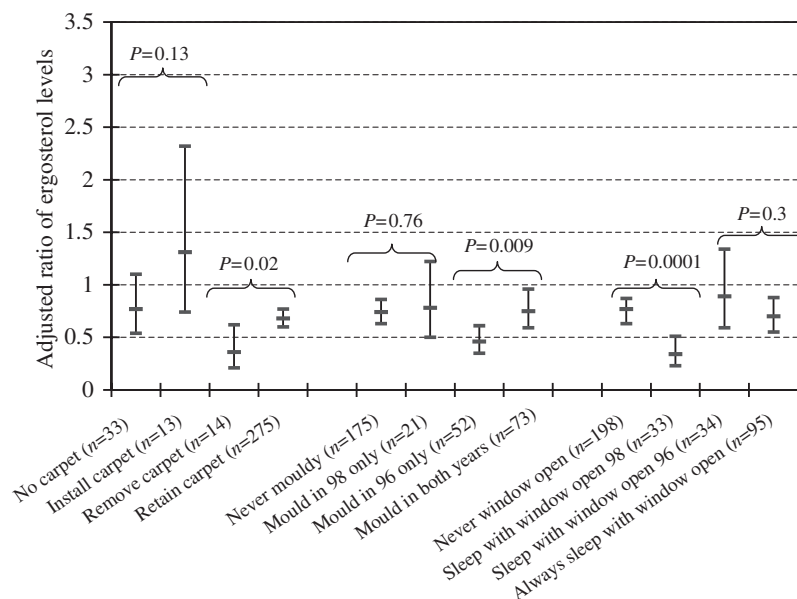


Fig. 4. Adjusted ratio of ergosterol levels in 1998 to 1996 for selected residential characteristics. (Adjusted for season sampled, relative humidity, fitted carpet, sleeping with windows open, windows open at time of sampling and mould in bedroom).

This model explained 33.3% of the variation in Fel d 1 levels. Those who moved to a freestanding home had a 7% increase in Fel d 1 levels. This was significantly different from the 45% reduction in Fel d 1 levels seen for those who remained in an attached home ($P = 0.004$). This model explained 30.9% of the variation in Fel d 1 levels. However this comparison lost significance when robust regression was used ($P = 0.145$).

Residential predictors of changes in ergosterol levels

The residential characteristics that were significant predictors of changes in ergosterol levels in house dust are presented in Fig. 4. Participants who removed fitted carpet in 1998 had a 64% decrease in ergosterol levels. This was significantly different from the 32% reduction in ergosterol levels seen for those who retained fitted carpet ($P = 0.03$). This model explained 14.8% of the variation in ergosterol levels. Participants who reported removing visible mould from their bedrooms by 1998 had 54% decrease in ergosterol levels. This was significantly different from participants who reported visible mould in both years, whose mean ergosterol levels only decreased 25% from 1996 to 1998 ($P = 0.009$). This model explained 15.3% of the variation in ergosterol levels. Participants who reported sleeping with the windows open only in 1998, had a 66% decrease in ergosterol levels from 1996 to 1998. This was significantly different from participants who never slept with the windows open, whose mean ergosterol levels decreased 26% only from 1996 to 1998 ($P < 0.0001$). This model explained 15.5% of the variation in ergosterol levels.

Residential predictors of change in fungal levels

None of the residential characteristics investigated in this study had any significant effect on changes in total fungal propagules or specific genera counts.

Discussion

This is the first study of which we are aware investigating longitudinal changes in residential characteristics as predictors of longitudinal changes in both allergen and fungal levels. We have found that the bed and floor Der p 1 levels, ergosterol and Fel d 1 levels were moderately well correlated between 1996 and 1998. On the other hand, the correlation between 1996 and 1998 in air borne fungal counts was negligible. The levels of Der p 1 in both bed and floor dust in 1996 were high and increased significantly by 1998. In both years, the mean levels were significantly above both the thresholds for sensitisation ($> 2 \mu\text{g/g}$) and symptom exacerbation ($> 10 \mu\text{g/g}$) that have been proposed previously [8]. These high Der p 1 levels are consistent with other studies of house dust mite allergen in Melbourne [3, 9].

We have found attached homes to have lower Der p 1 and Fel d 1 levels than freestanding homes. It has been suggested that attached dwellings or multifamily buildings are better ventilated, due to higher air exchange rates, than freestanding homes and therefore drier and less humid [10–12]. It has also been previously shown that having a space below the floor that is a room, rather than the ground or an underground basement, is associated with lower Der p 1 levels [13]. We found the base floor construction also significantly affected bed Der p 1 levels. This is consistent with previous cross-sectional studies that have found higher Der p 1 levels in homes with stumps and wooden floors [2, 13, 14]. It has been suggested that stumps and wooden flooring expose the indoor environment directly to underground moisture, while a concrete slab floor generally has a layer of plastic insulation between the slab and the ground, providing some protection. The importance of ground moisture is further highlighted by our finding of a substantial increase in Der p 1 levels in houses when the subject's bedroom moved to the ground floor and conversely a decrease when it moved to the first floor. Previous studies have also found associations between the

level of subjects' bedrooms and Der p 1 levels, which was attributed to exposure to underground moisture [15, 16].

Wall to wall carpets have been consistently associated with high Der p 1 levels [2, 14, 17–21]. We observed a highly significant increase in Der p 1 levels following installation and a significant decrease following removal of carpets. In addition, ergosterol levels were significantly reduced in homes of participants who removed carpets, which is consistent with cross-sectional studies [4]. These findings provide further evidence to support the current recommendation that removing carpets will reduce allergen load.

The effect of central heating on Der p 1 levels is complex with interactions between temperature, humidity and ventilation. Homes with central heating tend to have warmer drier environments, which are less favourable for mite growth [11]. We found that installing central heating resulted in a decrease in Der p 1 levels. Conversely it has also been suggested that central heating could lead to an increase in Der p 1 levels due to the absence of external ventilation [4], which may explain why we found that removing central heating also resulted in a decrease in Der p 1 levels.

We found that mattresses greater than 5 years old resulted in an increase in bed Der p 1 levels, which is consistent with previous cross-sectional studies [2, 15]. We also found that vacuuming the mattress at least twice per year significantly reduced Der p 1 levels, also consistent with cross-sectional studies [14]. Hence occasional vacuuming may be a simple alternative to mattress encasement for people with house dust mite allergy. We also found ergosterol levels to be significantly reduced by the removal of visible mould. Removal of mould growth has been suggested as an effective way to decrease indoor reserves of dead spores, which contribute to total airborne spore concentrations [4, 22]. Sleeping with the windows open was found to significantly reduce ergosterol levels. This is consistent with our cross-sectional study that also found fungal propagules originating outside have a strong influence on levels in the internal environment [4]. As would be expected, acquiring a cat was found to increase Fel d 1 levels substantially. Moving to a freestanding home was also found to lead to increased Fel d 1 levels. This was most likely attributable to less ventilation in freestanding homes compared to attached homes.

Nonetheless our study had some limitations. There was significant variation in the proportion of subjects who were visited in the same season in both 1996 and 1998. This is important given the seasonal variability in allergen and fungal levels. We observed a substantial decrease in Fel d 1 levels in 1998 that cannot be explained by variation in season. A possible explanation is the decrease in prevalence of cat ownership over the study period, however this still cannot fully explain the overall decrease observed. In 1996 we observed a significant increase in Der p 1 floor levels in summer and autumn, while in 1998 we found levels to be relatively consistent across all seasons. This may be due to a higher average summer temperature in 1998 than 1996 resulting in higher Der p 1 levels for the remainder of the year and on average higher Der p 1 levels in 1998.

Given the brief nature of the air sample collection, which was conducted over a 1-min period at a single time point in each year, it was not surprising that fungal measurements did not correlate well. Open windows and air circulation at the

time of sampling have an effect on airborne fungal propagule levels and therefore the amount of ergosterol in carpet dust [4, 23]. We observed fungal levels to be lower in 1998 than 1996, which is probably attributable to the fact that most participants in 1998 were visited in winter and spring, when outdoor fungal levels are at their lowest. We found ergosterol to be better correlated over time, providing a more stable indication of cumulative fungal exposure than air sampling.

We also used robust regression to assess whether individual or sets of data points markedly affected the results. On the whole these analysis supported the conclusions of the linear regression analysis. Overall our models explained between 10% and 30% of the variance in allergen levels observed over the study period, suggesting other factors also contribute to changes in allergen levels. Given the extensive variability in allergen levels observed in different climatic conditions, it is probably not surprising that residential characteristics explain only a relatively small proportion of the change in indoor allergen levels. However since a significant amount of time is spent indoors, residential characteristics remain an important way in which allergen exposures can be reduced.

In conclusion, our findings provide further evidence that residential characteristics are important determinants of indoor allergen levels. We can confirm that removing older carpet, investing in a new mattress at least every 5 years and vacuuming the mattress twice a year will reduce house dust mite levels. Removing damp patches and controlling indoor temperature and humidity will reduce fungal exposure. These findings provide evidence to support the current clinical advice with regard to allergen avoidance for patients with dust mite and fungal allergies.

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