Effects of Physical Interventions on House Dust Mite Allergen Levels in Carpet, Bed, and Upholstery Dust in Low-Income, Urban Homes

Patrick J. Vojta,[1] Sandra P. Randels,[2] James Stout,[2] Michael Muilenberg,[3] Harriet A. Burge,[3] Henry Lynn,[4] Herman Mitchell,[4] George T. O'Connor,[5] and Darryl C. Zeldin[1]

[1]Division of Intramural Research, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina, USA; [2]Department of Pediatrics, University of Washington, Seattle, Washington, USA; [3]Department of Environmental Health, Harvard School of Public Health, Boston, Massachusetts, USA; [4]Rho, Inc., Chapel Hill, North Carolina, USA; [5]Department of Medicine, Boston University School of Medicine, Boston, Massachusetts, USA

House dust mite allergen exposure is a postulated risk factor for allergic sensitization, asthma development, and asthma morbidity; however, practical and effective methods to mitigate these allergens from low-income, urban home environments remain elusive. The purpose of this study was to assess the feasibility and effectiveness of physical interventions to mitigate house dust mite allergens in this setting. Homes with high levels of house dust mite allergen (*Der f* 1 + *Der p* 1 ≥ 10 µg/g dust by enzyme-linked immunosorbent assay) in the bed, bedroom carpet, and/or upholstered furniture were enrolled in the study. Carpets and upholstered furniture were subjected to a single treatment of either dry steam cleaning plus vacuuming (carpet only) or intensive vacuuming alone. Bed interventions consisted of complete encasement of the mattress, box spring, and pillows plus either weekly professional or in-home laundering of nonencased bedding. Dust samples were collected at baseline and again at 3 days (carpet and upholstery only) and 2, 4, and 8 weeks posttreatment. We compared pretreatment mean allergen concentrations and loads to posttreatment values and performed between-group analyses after adjusting for differences in the pretreatment means. Both dry steam cleaning plus vacuuming and vacuuming alone resulted in a significant reduction in carpet house dust mite allergen concentration and load ($p < 0.05$). Levels approached pretreatment values by 4 weeks posttreatment in the intensive vacuuming group, whereas steam cleaning plus vacuuming effected a decrease that persisted for up to 8 weeks. Significant decreases in bed house dust mite allergen concentration and load were obtained in response to encasement and either professional or in-home laundering ($p < 0.001$). Between-group analysis revealed significantly less postintervention house dust mite allergen load in professionally laundered compared to home-laundered beds ($p < 0.05$). Intensive vacuuming and dry steam cleaning both caused a significant reduction in allergen concentration and load in upholstered furniture samples ($p < 0.005$). Based on these data, we conclude that physical interventions offer practical, effective means of reducing house dust mite allergen levels in low-income, urban home environments. *Key words*: allergen avoidance, asthma, environmental intervention, house dust mite, indoor allergens. *Environ Health Perspect* 109:815–819 (2001). [Online 6 August 2001]
http://ehpnet1.niehs.nih.gov/docs/2001/109p815-819vojta/abstract.html

A large body of evidence suggests that exposure to common indoor environmental allergens, including the house dust mite (HDM) allergens *Dermatophagoides pteronyssinus* allergen 1 (*Der p* 1) and *Dermatophagoides farinae* allergen 1 (*Der f* 1), is an important risk factor for allergic sensitization, asthma development, and asthma symptom exacerbation (*1–5*). Interventions to reduce HDM and food allergen exposure during the first 9 months of life have been reported to result in a decrease in the frequency of asthma, allergic rhinitis, and eczema at 12 months of age, suggesting that early allergen avoidance may indeed prevent the development of allergic diseases and asthma (*6*). However, the results from a recent prospective study of German children with/without a family history of atopy (*7*) have led some investigators to question the association between exposure to HDM allergen and the subsequent development of asthma. A number of secondary asthma prevention studies indicate that HDM allergen avoidance measures are effective at reducing HDM allergen exposure, asthma symptoms, and bronchial hyperreactivity in asthmatic children (*8–12*). Despite the reputed respiratory health benefits of indoor allergen avoidance, particularly for asthma patients (*13*), inexpensive, practical, and effective methods for home allergen control remain elusive (*14,15*). This may be especially true for residents of low-income, urban areas, who often have limited resources available to apply toward home allergen mitigation interventions.

The objective of this study was to test the feasibility and effectiveness of inexpensive, practical interventions to reduce indoor HDM allergen levels in the bed, bedroom carpeting, and upholstered furniture in low-income, urban homes. The primary end points were changes in HDM allergen concentrations (micrograms *Der p* 1 + *Der f* 1 per gram dust) and loads (micrograms *Der p* 1 + *Der f* 1 per sample) in posttreatment vacuumed dust compared to pretreatment values.

Materials and Methods

Recruitment, screening, and randomization. Low-income homes in the Seattle, Washington, metropolitan area were recruited through contacts with local neighborhood agencies and/or local city health centers. Eligible home types included single family detached houses, apartments in a free-standing building with three or fewer units, and apartments in complexes with three or more units. Informed consent was obtained from an adult member of each household, and the study protocol and all supporting documentation was approved by the Seattle Children's Hospital and Regional Medical Center Institutional Review Board. House dust samples collected from three sampling sites (a bed; a carpeted bedroom floor; and a frequently used upholstered sofa or chair) during a screening visit were subjected to allergen analysis. Homes that yielded "high" (defined as >10 µg total HDM allergen per gram of dust) allergen concentrations at any of the three sampling sites were randomized to one of the two intervention groups for that site.

Interventions. Intervention activities were implemented and overseen by field personnel who were extensively trained in environmental intervention methods for indoor allergen control in urban residences. Just before initiation of treatment, a baseline dust sample was collected and submitted for analysis to confirm screening sample results. Bed treatments consisted of encasement of pillows, box springs, and mattresses with HDM allergen-impermeable covers (Allergy Control Products, Ridgefield, CT) in conjunction with either professional or in-home laundering of all nonencased bedding materials.

Address correspondence to D.C. Zeldin, NIEHS, 111 Alexander Drive, Mail Drop D2-02, Research Triangle Park, NC 27709 USA. Telephone: (919) 541-1169. Fax: (919) 541-4133. E-mail: zeldin@niehs.nih.gov

We thank S. London and D. Morgan for helpful suggestions during preparation of this manuscript.

This work was funded by the National Institute of Environmental Health Sciences, Division of Intramural Research, and the National Institutes of Health, National Center for Minority Health and Health Disparities.

Received 20 November 2000; accepted 20 February 2001.

Participants assigned to the in-home laundry group received instructions to wash all bedding materials weekly in hot water using a detergent of their choice followed by hot drying. Participants in the professional laundry group were provided with bedding materials that had been washed weekly by a local cleaning company in hot water (> 140°F) containing approximately 0.5% S99 Detergent (Mt. Hood Chemical Corporation, Portland, OR) and 0.5% Orthotex (Diamond Chemical Company, East Rutherford, NJ). Homes enrolled in the carpet arm of the study received a single treatment of either intensive vacuuming only or steam cleaning combined with intensive vacuuming. The intensive vacuuming-only intervention was performed with a Miele Red-Star vacuum cleaner (Miele Company, Stuttgart, Germany) for 1 min/m^2 carpet in one direction and again at a rate of 1 min/m^2 carpet in the perpendicular direction. The vacuum was used in the powerhead-assisted mode with the rotating brush turned on. Dry steam cleaning was performed on carpeting with a Vaporjet 2400 steam cleaning machine (Advanced Vapor Technologies, Edmonds, WA) at a rate of 2.5 min/m^2 carpet according to the manufacturer's instructions for carpeting and was followed immediately with powerhead-assisted vacuuming at a rate of 30 sec/m^2 carpet. The Vaporjet 2400 applies hot steam (180°F) to the carpet and differs from standard hot water extraction cleaning methods in that the surface of the carpet is completely dry within 15 min of application. Moreover, the carpet backing remains dry throughout the procedure. Upholstered furniture was treated once by either intensive vacuuming only at a rate of approximately 2.5 min/m^2 surface area with a Miele Red-Star vacuum cleaner equipped with the manufacturer's upholstery attachment or by dry steam cleaning with a Vaporjet 2400 machine at a rate of 2.5 min/m^2 surface area according to the manufacturer's instructions for upholstery.

Dust sample collection and allergen analysis. Preintervention dust sample collections were performed at the screening visit and again 1–10 weeks later (mean 54 ± 7 days) at the baseline visit. Postintervention samples were collected at 3 days (carpet and upholstery only) and at 2, 4, and 8 weeks after initiation of the interventions. Indoor temperature and relative humidity were measured at each visit. Settled dust samples were collected with a Eureka Mighty-Mite 7.0 Ampere vacuum cleaner (Eureka Company, Bloomington, IL) fitted with 19-mm × 90-mm cellulose extraction thimbles (Whatman International, Ltd., Maidstone, England) in the distal end of the extension tube and a clean crevice tool. Bed samples were collected by vacuuming an area of 2 m^2 (the approximate area of a single twin-size bed) for a total of 5 min as follows: 1 min on one side of the pillow (over the pillowcase, if present); 2 min divided equally among the layers of blankets, sheets, and pads; and 2 min on the mattress surface. Impermeable covers were not removed from the mattress, if present. Bedroom floor samples were obtained by sampling a 2-m^2 carpeted floor area that included approximately 0.25 m^2 of under-bed area for a total of 5 min. Upholstery samples were collected by vacuuming 2 m^2 of upholstered chair or sofa surface for 5 min. These dust collection protocols are identical to those used in the National Allergen Survey and the Inner-City Asthma Study (*16*,*17*).

Dust samples were shipped to a central laboratory via overnight delivery. Within 2 working days of sample receipt, the dust was sieved through a 425-µm pore size grating, and the weight of the recovered fine dust was determined. Fine dust was extracted in borate buffered saline (pH 8.5), 2 mL/100 mg dust. Extracts were clarified by centrifugation at 1,300*g* and the supernatants were decanted and stored at –20°C until they were analyzed. Individual HDM allergens were measured using monoclonal antibody-based enzyme-linked immunosorbent assays (ELISAs) as described by Chapman et al. (*18*). The lower limit of detection was 0.025 µg allergen/g fine dust for both the *Der f* 1 and *Der p* 1 assays. Results are expressed as both concentration (micrograms HDM allergen per gram sieved dust) and load (micrograms HDM allergen per sample).

Statistical analyses. Combined *Der f* 1 plus *Der p* 1 values were log transformed before analysis. Within each treatment group, we performed a repeated measures analysis of covariance using season (July–September, October–December, January–March) and the difference in HDM allergen levels between screening and baseline as covariates and treating time (screening, baseline, 3 days, 2, 4, and 8 weeks) as the qualitative predictor. Contrasts were constructed to compare the mean posttreatment with mean pretreatment allergen levels. Between-treatment analyses were performed similarly using a repeated measures analysis of covariance, treating temperature, humidity, and pretreatment values as covariates. We used an average of the screening and the baseline values as the pretreatment level because there were no statistically significant differences between screening and baseline HDM allergen concentrations or loads at any of the three sites. We examined the difference between treatment types by comparing the adjusted mean posttreatment values between different treatment types.

Results

Of 39 homes screened for enrollment, 19 (49%) met allergen level enrollment criteria for one or more of the home intervention sites (bed, bedroom floor, or upholstery) and residents consented to participate in the study. Of these, 8 homes were enrolled for a single intervention site, 9 homes were enrolled for two sites, and 2 homes were enrolled for all three sites. All homes were freestanding, single-family dwellings and were enrolled between July 1998 and March 1999. All homes had wall-to-wall carpeting in the study bedroom and none of the homes used a fully encasing impermeable mattress or box spring cover on their bed before enrollment into the study.

Eleven homes were enrolled in the bedroom carpet intervention arm of the study; 6 were randomized to receive intensive vacuuming only and 5 were randomly assigned to receive dry steam cleaning plus intensive vacuuming. Both interventions resulted in significant posttreatment reductions in carpet HDM allergen concentration and load ($p < 0.05$; Figure 1). In the intensive vacuuming group, mean allergen concentrations decreased from a pretreatment value of 70.3 µg/g dust to 31.0 µg/g at 3 days postintervention, but increased to 59.5 µg/g by 4 weeks postintervention (Figure 1A). Similarly, mean

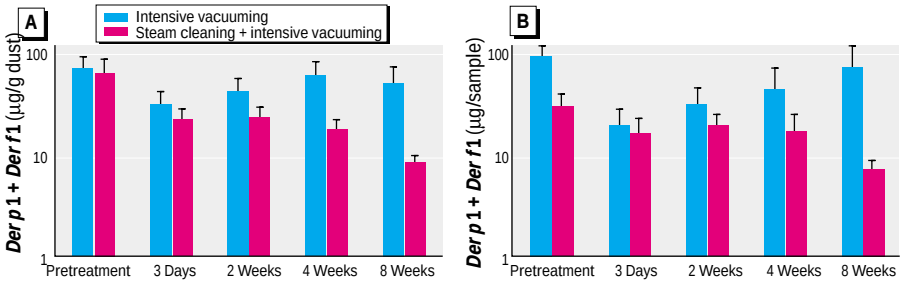

Figure 1. Effect of dry steam cleaning plus vacuuming versus intensive vacuuming alone on (*A*) carpet HDM allergen concentration and (*B*) load at 3 days and 2, 4, and 8 weeks posttreatment. Values represent treatment group means ± SE. Posttreatment within group decreases are statistically significant for both concentration and load ($p < 0.05$), although only the effect of steam cleaning plus vacuuming persists for up to 8 weeks. Between-group differences in the posttreatment concentration reductions are not statistically significant ($p = 0.07$).

HDM allergen load decreased from 90.2 µg/sample (pretreatment) to 19.5 µg/sample (3 days postintervention), but increased to 43.6 µg/sample by 4 weeks postintervention (Figure 1B). Together, these data indicate that the effect of intensive vacuuming was transient. In contrast, dry steam cleaning plus intensive vacuuming caused a significant decrease in mean HDM allergen concentration from 63.0 µg/g (pretreatment) to 22.0 µg/g (3 days postintervention), and the allergen concentration continued to decline through the 4-week (17.6 µg/g) and 8-week (8.2 µg/g) postintervention sampling periods (Figure 1A). Similarly, mean HDM allergen loads decreased from 29.0 mg/sample (pretreatment) to 7.0 mg/sample (8 weeks postintervention; Figure 1B). Between-treatment analysis revealed that there was a trend toward greater posttreatment reduction in mean allergen concentration ($p = 0.07$) in the dry steam cleaning plus intensive vacuuming group compared to the intensive vacuuming-only group. Importantly, only the combination of dry steam cleaning and vacuuming achieved HDM allergen concentrations below 10 µg/g dust, a level that is believed to be associated with excess asthma morbidity (*1*).

Bed interventions were implemented in 11 homes. All treated beds received allergen-impermeable box spring, mattress, and pillow covers. Weekly professional laundering of nonencased bedding materials was performed in 6 homes, whereas in-home laundering was performed on bedding materials in the remaining 5 homes. Both interventions resulted in significant posttreatment decreases in bed HDM allergen concentration and load ($p < 0.001$; Figure 2). In the in-home laundry group, mean allergen concentrations decreased from 53.5 µg/g dust (pretreatment) to 12.9 µg/g (2 weeks posttreatment), an effect that persisted through the 8-week sampling period (Figure 2A). Similarly, mean HDM allergen load decreased from 88.7 µg/sample (pretreatment) to 4.6 µg/sample (2 weeks postintervention) in this group (Figure 2B). In the professional laundry group, mean allergen concentrations decreased from 23.4 µg/g dust (pretreatment) to 3.4 µg/g (2 weeks posttreatment), an effect that also persisted through the 8-week sampling period (Figure 2A). Similar effects of professional laundering were observed for allergen load (Fig 2B). Between-treatment analysis revealed that the professional laundry group had a significantly greater posttreatment reduction in mean allergen load compared to the in-home laundry group ($p < 0.05$) and that there was a trend toward greater posttreatment reduction in mean allergen concentration in the professional laundry group versus the in-home laundry group ($p = 0.16$). Postintervention-seived dust weights were significantly lower in the professional versus in-home laundry group ($p = 0.02$).

Ten homes were enrolled in the upholstery intervention arm of the study; five were randomized to receive intensive vacuuming and five were randomly assigned to receive dry steam cleaning. Intensive vacuuming of upholstered furniture resulted in a significant posttreatment decrease in mean allergen concentration and load ($p < 0.001$; Figure 3). Mean concentration values decreased from 64.4 µg/g dust (pretreatment) to 14.8 µg/g at the 4-week posttreatment sampling point (Figure 3A). Similarly, mean load values decreased from 67.1 µg/sample (pretreatment) to 12.8 µg/sample at 4 weeks (Figure 3B). Dry steam cleaning also resulted in a significant posttreatment decrease in mean allergen concentration and load ($p < 0.005$; Figure 3). Between-group analysis indicated no significant difference in the effectiveness of intensive vacuuming versus dry steam cleaning for the mitigation of HDM allergen in upholstered furniture on the basis of either recovered allergen concentration or allergen load ($p > 0.5$).

There were no statistically significant differences in indoor relative humidity between the baseline exam and the four follow-up exams (F-test p-value = 0.37). Thus, none of the interventions affected relative humidity, assuming that no confounding seasonal or temporal effects were present.

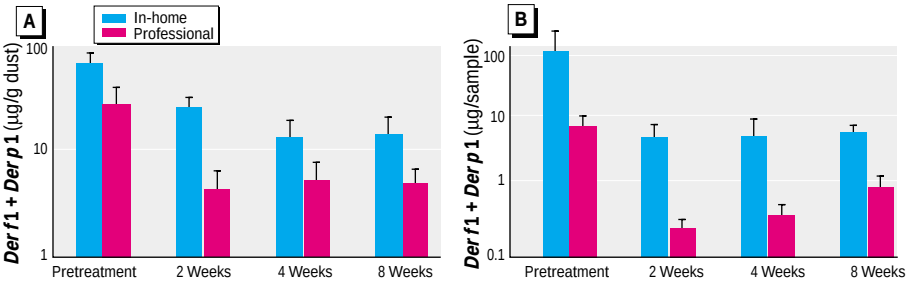

Figure 2. Effect of allergen-impermeable encasement of mattress, box spring, and pillows combined with either weekly professional or in-home laundry of nonencased bedding materials on (*A*) HDM allergen concentration and (*B*) load at 2, 4, and 8 weeks after initiation of intervention. Values represent treatment group means ± SE. Posttreatment within-group decreases are statistically significant for both concentration and load ($p < 0.001$). Between-group posttreatment decrease in allergen load is statistically significant ($p < 0.05$), but the decrease in allergen concentration is not ($p = 0.16$).

Discussion

In the National Cooperative Inner-City Asthma Study population, 49.4% of children's bedrooms had detectable levels of HDM allergen and 9.7% contained > 2 µg/g dust (*19*). Importantly, 34.6% of children in this study had positive skin tests to HDM (by comparison 35.8% had positive skin tests to cockroach allergens). Together, these data indicate that exposure to HDM is prevalent in urban areas in the United States. We have shown here that physical interventions can reduce HDM allergens in beds, bedroom carpeting, and upholstered furniture. We have demonstrated that these interventions can be implemented effectively in low-income, urban homes and that they can cause a reduction in both allergen concentration and load at sites of HDM allergen exposure and harborage. However, the effects of interventions in clinical trials are often greater than the differences between groups in cross-sectional community studies that apply these interventions as an every-day routine or not (*15*). These differences may be especially pronounced in low-income populations, where strict guidance by trained personnel may improve the intervention performance significantly. Thus, the conclusions of our study should be interpreted with caution.

Significant decreases in bedroom carpet allergens were achieved both by intensive vacuuming alone and by vacuuming in combination with steam cleaning. The decreases following a single vacuuming were transient, likely due to the minimal effect that vacuuming has on endogenous live HDM populations in carpet (*20*). Other groups have come to similar conclusions regarding the efficacy of vacuuming alone in reduction of carpet HDM allergen levels (*21,22*). Additionally, failure to remove all of the deep dust in an old carpet may confound cleaning studies that measure the reduction in load of HDM allergen on the surface of the carpet. Indeed, a recent study of intensive vacuuming in which only part of the deep dust was removed resulted in a 67% increase in HDM allergen loading on the carpet surface (*23*). In contrast, we found that dry steam cleaning resulted in a significant reduction in carpet HDM allergen that persisted for up to 8 weeks postintervention. These findings are consistent with the study by Colloff et al. (*24*), which showed that steam cleaning alone is an effective mitocidal treatment for carpets. Importantly, the steam cleaning procedures used in this study are both widely available and inexpensive to implement. Thus, dry steam cleaning followed by

intensive vacuuming may offer a simple, low-cost, nonchemical alternative to the use of acaricides in the management of HDM allergens in carpeting. Although removal of carpeting and replacement with smooth surfaces such as hardwood or vinyl remains the best method to reduce HDM allergens in flooring, this replacement method is expensive and may not be practical for residents of many low-income, urban homes.

Our results demonstrate that allergen-impermeable covers in combination with weekly laundering of nonencased bedding materials can result in reductions in bed HDM allergens, in accordance with results of previous tests of these methods (*5,9,15, 25–30*). The intervention that was implemented as part of this study resulted in bedding-dust HDM allergen concentrations < 10 µg/g, an exposure level threshold linked to asthma development (*1*) and acute asthma attacks (*31*). Between-group analysis indicated that changes in HDM allergen load were statistically better for the professional laundry arm versus the in-home laundry arm ($p = 0.03$), whereas changes in concentration were not ($p = 0.16$). Interestingly, dust weights were significantly lower in the professional versus in-home laundry arm ($p = 0.02$), suggesting that professional laundry services reduced the recovery of dust. These data also suggest that compliance rather than laundry method (e.g., detergents or other additives, wash water, or dryer temperature) was the main determinant of the difference in results. Given the additional cost associated with weekly professional laundry of bedding, this intervention may not be warranted in light of the modest difference in allergen reduction compared to home laundering, particularly in a low-income, urban environment.

Both dry steam cleaning and intensive vacuuming led to small reductions in HDM allergen in upholstered furniture, but, unlike the data obtained for bedroom carpets, the decrease effected by steam cleaning did not appear to persist any longer than that of intensive vacuuming alone. This apparent discrepancy may be due the physical properties of upholstery versus carpet materials. In particular, upholstery materials may not allow for complete steam penetration resulting in lower HDM mitigation efficacy. Alternatively, upholstery cushions may promote high residual humidity due to water retention after steam treatment, which may therefore lead to increased HDM growth over time.

One limitation of this study is that the effects were not controlled by observations in homes without interventions, so changes in allergen levels could be attributed, at least in part, to seasonal and/or temporal variations. Indeed, it is well established that HDM allergen levels can vary over time and during different seasons (*32,33*). We observed a 4- to 8-fold reduction in pretreatment allergen concentrations after interventions in homes enrolled between July–March and followed for 8 weeks. Platts-Mills et al. (*33*) observed that HDM levels were lowest between April and June but varied much less (generally 2- to 3-fold) during the period between July and March. Thus, the magnitude of the reductions in our study exceed those expected due to variations in season and other temporal factors. We also compared data from the screening and baseline visits, which were separated in time by a mean of 54 days. We found no statistically significant differences between the screening and the baseline HDM allergen concentrations or loads at any of the three sites. Thus, minimal variations in allergen levels occurred during this prestudy "control" period. Finally, we directly controlled for seasonal variations and differences in HDM allergen levels between screening and baseline by treating these factors as covariates in our repeated measures analysis.

Several environmental factors have been shown to be associated with concentrations of HDM allergens, including indoor temperature and humidity (*15,33,34*). We found no statistically significant differences in these variables between homes assigned to the different interventions for each of the three sites. Moreover, we directly controlled for differences in mean temperature and mean humidity across the baseline and follow-up exams by treating these factors as covariates in our between-treatment repeated measures analysis.

In summary, the results of this study in low-income, urban homes indicate that *a*) both intensive vacuuming alone and dry steam cleaning plus vacuuming can result in significant reductions in HDM allergens in bedroom carpet, with the combined modality producing a longer duration effect; *b*) impermeable covers combined with frequent washing of nonencased bedding materials can significantly reduce HDM allergen levels in the bed; and *c*) both intensive vacuuming and steam cleaning have a modest effect on HDM levels in upholstered furniture. The professional laundry bedding regimen and the carpet steam cleaning plus vacuuming method are effective at decreasing HDM allergens to levels below those associated with increased asthma morbidity, but not below the 2 µg/g threshold proposed as an allergen sensitization risk factor (*31,35*). These physical interventions will likely have to be repeated often to maintain modest, long-term HDM allergen control. It remains to be shown that controlling HDM allergen in the absence of cockroach control in the inner city will have an effect on asthma prevalence and/or morbidity.

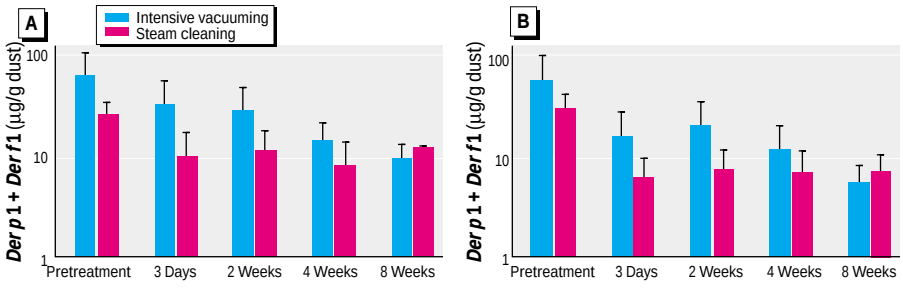

Figure 3. Effect of dry steam cleaning versus intensive vacuuming on (*A*) upholstery HDM allergen concentration and (*B*) load at 3 days and 2, 4, and 8 weeks posttreatment. Values represent treatment group means ± SE. Posttreatment within-group decreases are statistically significant for both concentration and load ($p < 0.005$). Between-group differences in the posttreatment concentration reductions are not statistically significant.

References and Notes

1. Sporik R, Holgate ST, Platts-Mills TAE, Cogswell JJ. Exposure to house-dust mite allergen (*Der p 1*) and the development of asthma in childhood: a prospective study. N Engl J Med 323:502–507 (1990).
2. Hide DW, Matthews S, Matthews L, Stevens M, Ridout S, Twiselton R, Gant C, Arshad SH. Effect of allergen avoidance in infancy on allergic manifestations at age two years. J Allergy Clin Immunol 93:842–846 (1994).
3. Chan-Yeung M, Manfreda J, Dimich-Ward H, Lam J, Ferguson A, Warren P, Simons E, Broder I, Chapman M, Platts-Mills T, Becker A. Mite and cat allergen levels in homes and severity of asthma. Am J Respir Crit Care Med 152:1805–1811 (1995).
4. Henderson FW, Henry MM, Ivins SS, Morris R, Neebe EC, Leu S-Y, Stewart PW. Correlates of recurrent wheezing in school-age children. Am J Respir Crit Care Med 151:1786–1793 (1995).
5. Custovic A, Taggart SCO, Francis HC, Chapman MD, Woodcock A. Exposure to house dust mite allergens and the clinical activity of asthma. J Allergy Clin Immunol 98:64–72 (1996).
6. Arshad SH, Matthews S, Gant C, Hide DW. Effect of allergen avoidance on development of allergic disorders in infancy. Lancet 339:1493–1497 (1992).
7. Lau S, Illi S, Sommerfeld C, Niggemann B, Bergmann R, von Mutius E, Wahn U. Early exposure to house-dust mite and cat allergens and development of childhood asthma: a cohort study. Lancet 356:1392–1397 (2000).
8. Murray AB, Ferguson AC. Dust-free bedrooms in the treatment of asthmatic children with house dust or house dust mite allergy: a controlled trial. Pediatrics 71:418–422 (1983).
9. Ehnert B, Lau-Schadendorf S, Weber A, Buettner P, Schou C, Wahn U. Reducing domestic exposure to dust mite allergen reduces bronchial hyperreactivity in sensitive children with asthma. J Allergy Clin Immunol 90:135–138 (1992).

10. Platts-Mills TAE, Tovey ER, Mitchell EB, Moszoro H, Nock P, Wilkins SR. Reduction of bronchial hyperreactivity during prolonged allergen avoidance. Lancet 2:675–678 (1982).
11. Walshaw MJ, Evans CC. Allergen avoidance in house dust mite sensitive adult asthma. Q J Med 58:199–215 (1986).
12. Dorward AJ, Colloff MJ, MacKay NS, McSharry C, Thomson NC. Effect of house dust mite avoidance measures on adult atopic asthma. Thorax 43:98–102 (1988).
13. Eggleston PA, Creticos PS, Lockey R, Platts-Mills TAE, Sheffer A, Taggart VS, Shapas TJ, Clobes A, Scheuttenberg W, Shapas TJ. Environmental allergen avoidance in allergic asthma. J Allergy Clin Immunol 103:203–205 (1999).
14. Woodfolk JA, Hayden ML, Couture N, Platts-Mills TA. Chemical treatment of carpets to reduce allergen: comparison of the effects of tannic acid and other treatments on proteins derived from dust mites and cats. J Allergy Clin Immunol 96:325–333 (1995).
15. Tovey E, Marks G. Methods and effectiveness of environmental control. J Allergy Clin Immunol 103:179–191 (1999).
16. Zeldin DC, Vojta PJ, Friedman W, Zhou J, Yin M, Schuelt E, Cohn R, Burge H, Muilenberg M, Thorne PS. Factors associated with dust mite allergen exposure in bed: results from the first National Allergen Survey. Am Rev Resp Crit Care Med 163:A722 (2001).
17. Mitchell H, Senturia Y, Gergen P, Baker D, Joseph C, McNiff-Mortimer K, Wedner HJ, Crain E, Eggleston P, Evans R III, et al. Design and methods of the National Cooperative Inner City Asthma Study. J Pediatr Pulmonol 24:237–252 (1997).
18. Chapman MD, Heymann PW, Wilkins SR, Brown MJ, Platts-Mills TA. Monoclonal immunoassays for major dust mite (*Dermatophagoides*) allergens, *Der p* 1 and *Der f* 1, and quantitative analysis of the allergen content of mite and house dust extracts. J Allergy Clin Immunol 80:184–194 (1987).
19. Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin RG, Gergen P, Mitchell H, McNiff-Mortimer K, Lynn H, Ownby D, et al. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. N Engl J Med 336:1356–1363 (1997).
20. Wassenaar DPJ. Effectiveness of vacuum cleaning and wet cleaning on reducing house-dust mites, fungi, and mite allergen in a cotton carpet: a case study. Exp Appl Acarol 4:53–62 (1988).
21. Munir AK, Einarsson R, Dreborg SK. Vacuum cleaning decreases the levels of mite allergens in house dust. Pediatr Allergy Immunol 4:136–143 (1993).
22. Adilah N, Fitzharris P, Crane J, Siebers RW. The effect of frequent vacuum cleaning on the house dust mite allergen, *Der p 1* in carpets: a pilot study. NZ Med J 110:438–439 (1997).
23. Roberts JW, Clifford WS, Glass G, Hummer PG. Reducing dust, lead, dust mites, bacteria, and fungi in carpets by vacuuming. Arch Environ Contam Toxicol 36:477–484 (1999).
24. Colloff MJ, Taylor C, Merrett TG. The use of domestic steam cleaning for the control of house dust mites. Clin Exp Allergy 25:1060–1061 (1995).
25. Owen S, Morganstern M, Hepworth J, Woodcock A. Control of house dust mite antigen in bedding. Lancet 335:396–397 (1990).
26. McDonald LG, Tovey E. The role of water temperature and laundry procedures in reducing house dust mite populations and allergen content of bedding. J Allergy Clin Immunol 90:599–608 (1992).
27. Tovey E, Marks G, Shearer M, Woodcock A. Allergens and occlusive bedding covers [Letter]. Lancet 342:126 (1993).
28. Kemp TJ, Siebers RW, Fishwick D, O'Grady GB, Fitzharris P, Crane J. House dust mite allergen in pillows. Br Med J 313:916 (1996).
29. Miller JD, Miller A. Ten minutes in a clothes dryer kills all mites in blankets. J Allergy Clin Immunol 97:962 (1996).
30. Platts-Mills TAE, Vervloet D, Thomas WR, Aalberse RC, Chapman MD. Indoor allergens and asthma: report of the third international workshop. J Allergy Clin Immunol 100:S1–S24 (1997).
31. Platts-Mills TAE, De Weck A. Dust mite allergens and asthma—a world wide problem. Bull WHO 66:769–780 (1989).
32. Hirsch T, Kuhlisch E, Soldan W, Leupold W. Variability of house dust mite allergen exposure in dwellings. Environ Health Perspect 106:659–664 (1998).
33. Platts-Mills TAE, Hayden ML, Chapman MD, Wilkins SR. Seasonal variation in dust mite and grass-pollen allergens in dust from the houses of patients with asthma. J Allergy Clin Immunol 79:781–791 (1987).
34. Custovic A, Simpson A, Chapman MD, Woodcock A. Allergen avoidance in the treatment of asthma and atopic disorders. Thorax 53:63–72 (1998).
35. Platts-Mills TAE, Thomas WR, Aalberse RC, Vervloet D, Champman MD. Dust mite allergens and asthma: report of a second international workshop. J Allergy Clin Immunol 89:1046–1060 (1992).