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Effect of an Air Cleaner with Electrostatic Filter on the Removal of Airborne House Dust Mite Allergens

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Purpose: The effects of air cleaners on the removal of airborne indoor allergens, especially house dust mites (HDM), are still controversial. The objective of this study is to evaluate the effect of an air cleaner with an electrostatic filter on the removal of airborne mite allergens. **Materials and Methods:** A dried HDM culture medium that contained mite body particles and excretions was dispersed in a chamber equipped with an electrostatic air cleaner. The number of airborne particles was recorded continuously by a dust spectrometer for 60 minutes. Airborne particles in the chamber were collected on a sampling filter at a flow rate of 10 L/min and the Der f 1 concentration in the filter extracts was measured by two-site ELISA. **Results:** The air cleaner efficiently removed airborne HDM particles. The air cleaner removed airborne HDM particles (size 2-12.5 μm) 11.4 ± 2.9 fold (cleaner operating for 15 minutes), 5.4 ± 0.7 fold (cleaner operating for 30 minutes), and 2.4 ± 0.2 fold (cleaner operating for 60 minutes) more than the removal of HDM particles by natural settle down. Removal kinetics differed according to the particle size of the airborne particles. The air cleaner decreased the concentration of Der f 1 in the extraction of airborne particles collected on the air sampling filter by 60.3%. **Conclusion:** The electrostatic air cleaner can remove airborne HDM allergens and may be useful as a supplementary environmental control tool for HDM sensitized respiratory allergic patients.

Key Words: House dust mite, electrostatic air cleaner, environmental control

INTRODUCTION

Indoor air quality has received increasing attention in recent years due to the global increase in allergic diseases. Researchers have investigated the relationship between the level of environmental exposure to house dust mites (HDM) and sensitization to and development of certain allergic diseases.[1,2] Although naturally-occurring aeroallergens are difficult to avoid, exposure to these allergens may be reduced, often substantially, by environmental control measures such as encasing bedding materials and pillows, air cleaners, and ventilation.[3] Use of an high efficiency particle arrest (HEPA) air cleaner to reduce airborne allergens in the indoor environment may provide clinical benefits for patients with respiratory allergies; these HEPA air cleaners have been demonstrated to reduce levels of airborne pet allergens.[4,5] However, the ability of air cleaners to remove HDM and other allergens is still controversial.[4,5,6-10] Electrostatic air cleaners remove airborne particles by charging the airborne particles and then trapping them on oppositely charged metal plates. The efficiency of the HEPA air cleaner has been reported to be better than electrostatic air cleaners, and most clinical studies with allergic patients were done with HEPA air cleaners. However, HEPA cleaners are noisy and require regular changing of expensive HEPA filters. The objective of this study was to evaluate the ability of an air cleaner equipped with electrostatic filter to remove airborne HDM particles.

MATERIALS AND METHODS

Study design

We evaluated the efficiency of electrostatic air cleaner by comparing the concentrations of HDM particles in the closed chamber measured by spectrophotometer and the amount of HDM particles in the glass filter collected by constant flow air sampler in the chamber. We compared these two parameters measured at the on and off statuses of the air cleaner.

Air cleaner and sample preparation

To create a source of house dust mite particles, we dried 30 g of culture medium containing *Dermatophagoides farinae* at room temperature for 24 hours. *D. farinae* was cultured at 25 ± 3˚C and 75 ± 2% relative humidity. One gram of the culture medium contained 9.6 μg of Der f 1. An LG air cleaner with an electrostatic filter (LG Electronic, Changwon, Korea), embedded into an air conditioner, was used in this study. However, the air conditioner was off during the experiment. The airflow of the air cleaner was 10 m^3/min and it was equipped with two different filters: an electrostatic filter and a fine mesh mechanical pre-filter. The dust removal efficiency of the electrostatic filter and fine mesh mechanical pre-filter was about 50% and 35%, respectively, as calculated by the one-pass method using a particle counter ($PM_{2.5}$) at the velocity of 5.3 cm/sec.

Measurement of airborne particles using dust spectrometer

A closed stainless steel chamber (30.4 m^3) was first cleared by air circulation and a HEPA filter system and the particle concentration was monitored until it reached a baseline of less than 104 particle/m^3 for 2-12.5 μm size range. A total of 150 mg of the allergen particles were loaded into a suction type particle feeder and then dispersed at 30 L/min spraying velocity for 1 minute. The number of airborne particles during each experiment was measured using a particle sampling unit installed 1 m above the chamber floor at the center of the chamber. The unit was connected to an optical particle counter (Portable Aerosol Spectrometer, Model 1.109, Grimm Aerosol Technik, Ainring, Germany) and data was analyzed using a particle concentration analyzing program (Version 3.20 build 6, Grimm Aerosol Technik, Germany). Distribution of the particles immediately after dispersion of 0.15 gm of the medium is shown Fig. 1. The distribution was expressed as a volume ($\mu m^3/m^3$) or number of particles (/m^3) per volume of the chamber. The number of the airborne particles was recorded every minute for 60 minutes. These experiments were done triplicate.

Calculation of Clean Air Delivery Rates (CADRs)

The air cleaning performance with the LG air cleaner was represented by a Clean Air Delivery Rate (CADR) which determines how well an air cleaner reduces airborne particles.[11,12] The CADR of the air cleaner to remove the airbone particles is based on the below formula.

$$C_{t,i} = C_i e^{-kt}$$

Abbreviations; where C_t, = concentration at time t (particles/m^3), k = decay rate constant (min^{-1}), and t = time

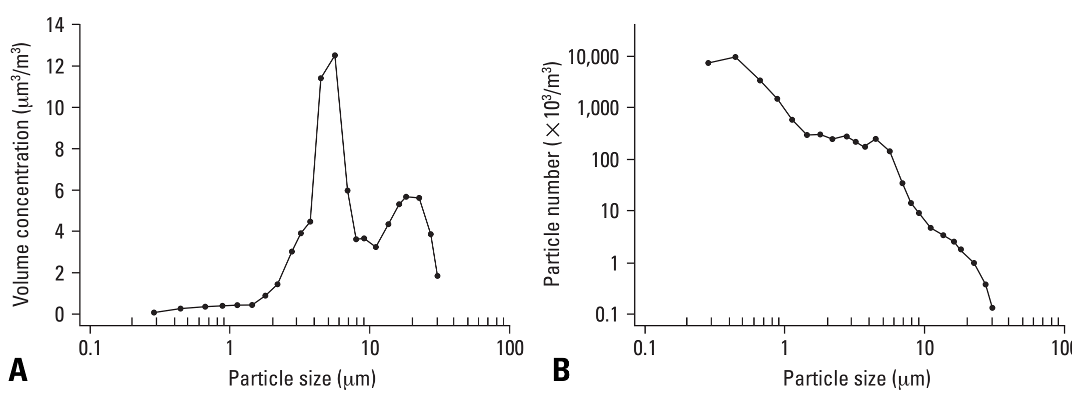

Fig. 1. Distribution of airborne particles per size immediately after dispersion of the 150 mg of culture media at the closed chamber. It was expressed with the volume of the particles (A) or number of particles (B) per m^3 according to the size of the particles.

(minutes).

The decay constant, k, is obtained by fitting a linear regression line to the slope of $-\ln(C(t)/C_0)$, which is the negative of the natural log of the time-varying particle concentration ($C(t)$) normalized by the initial concentration at the time the incense was extinguished (C_0), versus time (h). The CADR of airborne particles was calculated by the below formula.

$$CADR = V \times k$$

Abbreviations; V = volume of test chamber (m^3), k = measured decay rate, min^{-1}.

Measurement of the concentration of Der f 1 from the air sampling filters

Airborne particles in the closed chamber were collected on glass fiber filter paper (Model GF/C Φ47 mm, Whatman, UK, pore size; 1.6 μm) at a flow rate of 10 L/min for 30 minutes after the concentrations of HDM particles reached the maximum values. During the experiments, the air cleaner and the air sampler worked simultaneously. The HDM allergens were extracted from the filter paper with borate buffered saline (BBS) (170 mM boric acid, 125 mM NaCl, pH 7.0) for 18 hr at room temperature with gentle shaking. The Der f 1 concentrations in each extracted solution were measured by 2-site ELISA (Indoor biotechnologies, Manchester, UK) following the manufacturer's recommendations, except that 3,3'-5,5'-tetramethylbenzidine (TMB, Kirkegaard & Perry Laboratories, Gaithersburg, MD, USA) were used as a substrate instead of ABTS. The detection limit for Der f 1 was 60 pg/mL. These experiments were done triplicate.

Statistical analysis

The Mann-Whitney U-test was used to compare the Der f 1 level or CADR value between the samples. The Wilcoxon Sign Ranked test was used to compare the fold-removal rate in comparison with the baseline. Significance was set up at $p < 0.05$. All statistical analysis was performed with SPSS 12.0 (SPSS Inc., Chicago, IL, USA). Bars in the figures indicate the standard error of the mean.

RESULTS

Removal efficiency of the air cleaner measured by dust spectrometer

HDM airborne particles between the size ranges of 10.0-12.5, 5.0-6.5, and 2.0-2.5 μm were rapidly removed by the

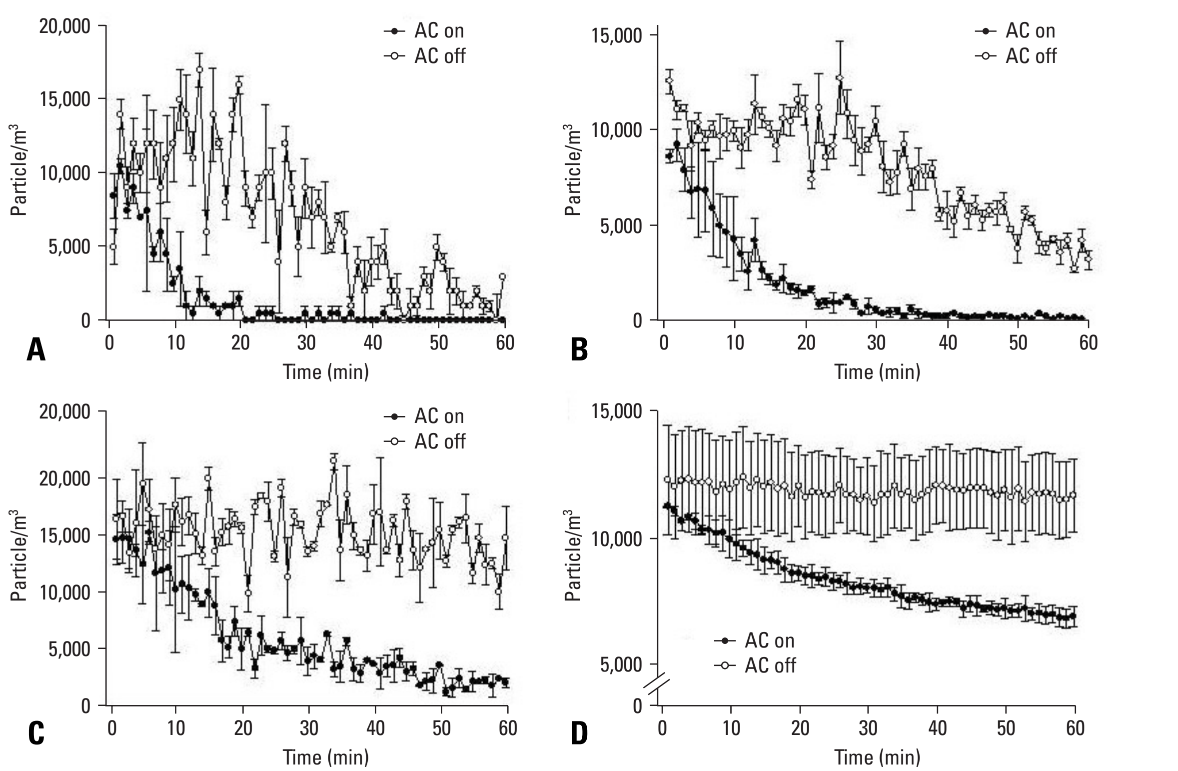

Fig. 2. Removal efficiency of the split electrostatic and fine mesh mechanical pre-filter air cleaner. The size and number of HDM particles were measured using a dust spectrometer. (A) HDM particles in the size range 10.0 - 12.5 μm. (B) HDM particles in the size range 5.0 - 6.5 μm. (C) HDM particles in the size range 2.0 - 2.5 μm. (D) HDM particles in the size range 0.25 - 0.28 μm. The bars in these figures represent standard error of the mean. HDM, house dust mites.

split electrostatic and fine mesh mechanical air cleaner (Fig. 2). Fig. 2 shows the efficiency of the cleaner at different time points. The cleaner removed airborne HDM particles (size 2-12.5 μm) in the chamber 11.4 ± 2.9 fold (cleaner operating for 15 minutes), 5.4 ± 0.7 fold (cleaner operational for 30 minutes), and 2.4 ± 0.2 fold (cleaner operating for 60 minutes) more than particle removal by natural settling. By running the cleaner for 30 minutes, 79.9 ± 2.6% of HDM particles (2-12 μm) were removed compared to the 9.7 ± 5.0% of HDM particles removed by natural settling. Approximately 64.3% of the HDM particles (size 2-12.5 μm) were still airborne 60 minutes after the concentration of the HDM particles, sprayed from the particle feeder; use of the air cleaner reduced this value to 10% (Fig. 3).

Measurement of CADRs

Significant differences in removal kinetics were found according to the size of airborne particles. The air cleaner completely removed larger particles between 10-12.5 μm within 30 minutes. The CADRs were particle size-dependent and the difference between the CADRs with and without the air cleaner operation dramatically increased as the size of the particles were larger (Fig. 4). Particles larger than 15 μm settled down so rapidly that they could not be accurately measured using the dust spectrometer (data not shown).

Measurement of airborne Der f 1 with or without air cleaner

The concentration of airborne Der f 1 in the chamber was markedly decreased by the air cleaner as shown in Fig. 5. The Der f 1 concentration in the extract solution of the air-sampling filter was 47.2 ± 7.5 ng/mL when the air cleaner was used, as compared to 118.75 ± 14.12 ng/mL when the air cleaner was not used, indicating that the air cleaner decreased the Der f 1 concentration by 60.3%.

DISCUSSION

Our study shows that the use of an air cleaner with electrostatic filters can reduce the exposure to HDM particles of several sizes. Air cleaners can reduce airborne Can f 1 or Fel d 1,[4-5,10] but few studies have investigated the ability of these cleaners to remove airborne or settle down HDM allergens, and the clinical effects of air cleaners for reducing the exposure to HDM are questionable.[3,6,7] In this study, an air cleaner with electrostatic filters removed larger HDM particles of sizes (10-12.5 μm) within 30 minutes and markedly reduced the concentration of smaller particles

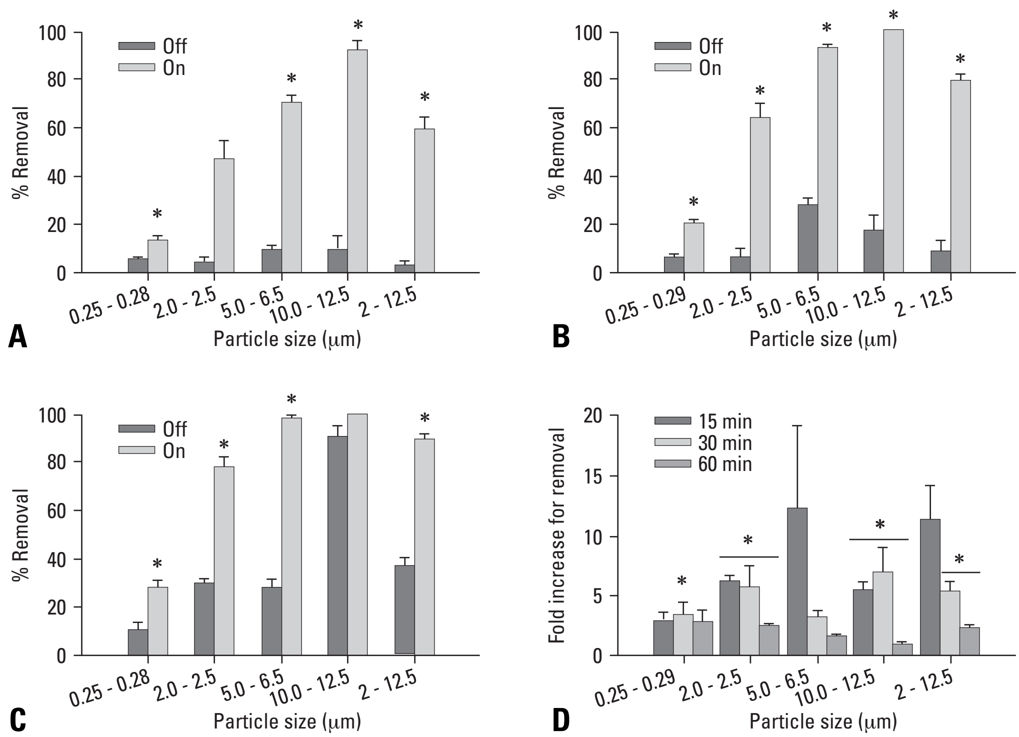

Fig. 3. Removal efficiency of the air cleaner expressed as the percentage removal of airborne HDM particles in the chamber. The baseline value is the concentration of particles immediately after spraying. (A) Removal efficiency after 15 minutes. (B) Removal efficiency after 30 minutes. (C) Removal efficiency after 60 minutes. Black bars in A-C represent the rate of settlement of HDM particles. D shows the fold-increase in HDM removal by the cleaner compared to the natural settlement. The dotted line represents 1 fold indicating natural settlement. Bars in these figures represent standard errors of the mean. *$p < 0.05$.

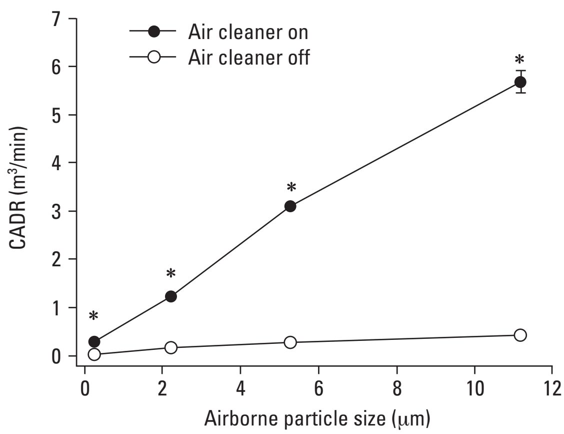

Fig. 4. CADR values of the electrostatic and fine mesh mechanical pre-filter air cleaner according to the size of airborne particles. CADR values are airborne particle size dependent. The bars in this figure represent standard error of the mean. *$p<0.05$. CADR, Clean Air Delivery Rate.

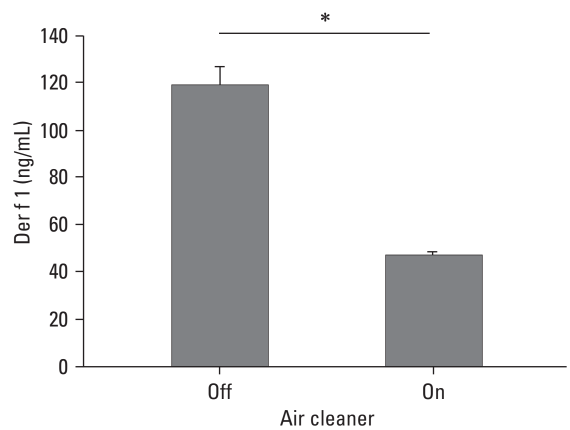

Fig. 5. Concentration of Der f 1 in extracts from the air sampling filters installed in a closed chamber with or without air cleaner. The bars in this figure represent standard error of the mean. *$p<0.05$.

(2-10 μm) within 60 minutes. These results may suggest that electrostatic air cleaners may reduce the exposure of inhabitants to HDM allergens. As the removal of the airborne particles by an electrostatic cleaner is governed by impaction, electrical charging and interception of the airborne particles on the filter, efficiency of removal of airborne particles depends on the physical size of the particles. Generally, removal of larger particles is easier than that of smaller particles.[13] The CADR values for airborne particles in the ranges of 5-12.5 μm, critical ranges for HDM allergens, were superior to the values of smaller particles in this study. It is noteworthy that 60% of airborne Der f 1 was removed by the air cleaner within 30 minutes.

More than 80% of airborne particles, including HDM fecal material, are usually larger than 10 μm[14-16] and the fecal material has been recognized as the major sources of the HDM allergen.[17] These findings raise a question of how HDM aggravates asthma in patients with HDM sensitization. Aerodynamically larger particles (> 10 μm) usually do not reach the peripheral airway, and encasings with pore sizes less than 10 μm are effective in blocking dust mite allergens.[18] However, Svartengren, et al.[19] demonstrated that 4% to 15% of inhaled large Teflon particles ranging from 8.2 to 13.7 μm were deposited in the alveoli, confirming that large particles can be deposited in the peripheral airways. Although the majority of HDM particles in homes are larger than 10 μm, this does not decrease the significance of small HDM particles in asthmatic patients. Custovic, et al.[20] showed that group 2 dust mite allergens are carried not only on large particles but also on small particles (< 5 μm). Furthermore, HDM had more than 15 major allergens, and the aerodynamic characteristics of these allergens may be different. HDM allergens have been shown to be present in the lower airway of most HDM sensitized asthmatic patients. HDM allergens have been identified in BAL fluid at low concentrations.[21] De Lucca, et al.[22] demonstrated that Der p 1 is associated with particles not ranging from feces, to fibers, to flakes, which are all sources of inhaled mite aeroallergens. The particle sizes of the culture medium used in this study was not that different from the HDM particles in the house dust. The median size of the particles (in the aspect of volume concentration) used in this study fell in the range of 4-8 μm, and a considerable amount of particles were larger than 10 μm.

Although the air cleaner cannot efficiently reduce exposure to HDM particles during sleep, settled dust is likely to be disturbed by various living activities of inhabitants during the day, and under these circumstances, the air cleaner may protect inhabitants from exposure to HDM. The HEPA filter can remove 99.9% of airborne particles 0.3 μm in size by passing through the filter, but the performance of the air cleaner is expressed as the CADR that takes into account both the flow rate through the air cleaner and the filter efficiency.[23,24] HEPA air cleaners have some weak points. Noise is one drawback of the HEPA air cleaner, and it requires high energy costs. Pressure drop is another drawback. As the air particles are deposited into the HEPA filter, the air flow rate decreased. In spite of a lower filtration efficiency of the electrostatic filter than that of the HEPA, the electrostatic filter may permit higher air flow rates due to a smaller pressure drop than that with the HEPA filter. Furthermore, we showed that the levels of airborne Der f 1 could be reduced using an electrostatic air cleaner in this study.

This study has several limitations. Measurements were taken in a closed chamber in which HDM particles from the culture medium had been sprayed. These experimental conditions do not reflect a real living environment. Furthermore, we only measured indirect parameters to assess the effects of the air cleaner. Further clinical studies are needed to determine the clinical usefulness of the air cleaner.

In conclusion, an electrostatic air cleaner can remove airborne HDM allergens and may be useful for the management of respiratory allergies in patients sensitized to HDM allergens.

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REFERENCES

1. Sporik R, Holgate ST, Platts-Mills TA, Cogswell JJ. Exposure to house-dust mite allergen (Der p I) and the development of asthma in childhood. A prospective study. N Engl J Med 1990;323:502-7.
2. Wahn U, Lau S, Bergmann R, Kulig M, Forster J, Bergmann K, et al. Indoor allergen exposure is a risk factor for sensitization during the first three years of life. J Allergy Clin Immunol 1997;99:763-9.
3. Eggleston PA. Improving indoor environments: reducing allergen exposures. J Allergy Clin Immunol 2005;116:122-6.
4. Wood RA, Johnson EF, Van Natta ML, Chen PH, Eggleston PA. A placebo-controlled trial of a HEPA air cleaner in the treatment of cat allergy. Am J Respir Crit Care Med 1998;158:115-20.
5. Green R, Simpson A, Custovic A, Faragher B, Chapman M, Woodcock A. The effect of air filtration on airborne dog allergen. Allergy 1999;54:484-8.
6. Reisman RE, Mauriello PM, Davis GB, Georgitis JW, DeMasi JM. A double-blind study of the effectiveness of a high-efficiency particulate air (HEPA) filter in the treatment of patients with perennial allergic rhinitis and asthma. J Allergy Clin Immunol 1990;85:1050-7.
7. Antonicelli L, Bilò MB, Pucci S, Schou C, Bonifazi F. Efficacy of an air-cleaning device equipped with a high efficiency particulate air filter in house dust mite respiratory allergy. Allergy 1991;46:594-600.
8. Reisman RE. Do air cleaners make a difference in treating allergic disease in homes? Ann Allergy Asthma Immunol 2001;87:41-3.
9. Sheikh A, Hurwitz B, Shehata Y. House dust mite avoidance measures for perennial allergic rhinitis. Cochrane Database Syst Rev 2007;24:CD001563.
10. Sulser C, Schulz G, Wagner P, Sommerfeld C, Keil T, Reich A, et al. Can the use of HEPA cleaners in homes of asthmatic children and adolescents sensitized to cat and dog allergens decrease bronchial hyperresponsiveness and allergen contents in solid dust. Int Arch Allergy Immunol 2009;148:23-30.
11. Waring MS, Siegel JA, Corsi RL. Ultrafine particle removal and generation by portable air cleaners. Atmos Environ 2008;42:5003-14.
12. Association of Home Appliance Manufacturers (AHAM). AHAM method for measuring performance of portable household electric room air cleaners. ANSI/AHAM AC-1-2006; Revision of ANSI/AHAM AC-1-2002 and AHAM AC-1-2005. Washington DC: 2006. p.16-9.
13. Hinds WC, Aerosol technology: properties, behaviors, and measurement of airborne particles. New York: Wiley-Interscience Publication;1998.
14. Tovey ER, Chapman MD, Wells CW, Platts-Mills TA. The distribution of dust mite allergen in the houses of patients with asthma. Am Rev Respir Dis 1981;124:630-5.
15. de Blay F, Heymann PW, Chapman MD, Platts-Mills TA. Air borne dust mite allergens: comparison of group II allergens with group I mite allergen and cat-allergen Fel d 1. J Allergy Clin Immunol 1991;88:919-26.
16. Platts-Mills TAE, Heymann PW, Longbottom JL, Wilkins SR. Airborne allergens associated with asthma: particle sizes carrying dust mite and rat allergens measured with a cascade impactor. J Allergy Clin Immunol 1986;77:850-7.
17. Tovey ER, Chapman MD, Platts-Mills TA. Mite faeces are a major source of house dust allergens. Nature 1981;289:592-3.
18. Vaughan JW, McLaughlin TE, Perzanowski MS, Platts-Mills TA. Evaluation of materials used for bedding encasement: effect of pore size in blocking cat and dust mite allergen. J Allergy Clin Immunol 1999;103:227-31.
19. Svartengren M, Falk R, Linnman L, Philipson K, Cammer P. Deposition of large particles in human lung. Exp Lung Res 1987;12:75-88.
20. Custovic A, Woodcock H, Craven M, Hassall R, Hadley E, Simpson A, et al. Dust mite allergens are carried on not only large particles. Pediatr Allergy Immunol 1999;10:258-60.
21. Ferguson P, Brodie DH. Environmental and bronchoalveolar lavage Dermatophagoides pteronyssinus antigen levels in atopic asthmatics. Am J Respir Crit Care Med 1995;151:71-4.
22. De Lucca S, Sporik R, O'Meara TJ, Tovey ER. Mite allergen (Der p 1) is not only carried on mite feces. J Allergy Clin Immunol 1999;103:174-5.
23. Fox RW. Air cleaners: a review. J Allergy Clin Immunol 1994;94:413-6.
24. Shaughnessy RJ, Sextro RG. What is an effective portable air cleaning device? A review. J Occup Environ Hyg 2006;3:169-81.