ORIGINAL ARTICLE

Two Routes for Pollen Entering Indoors: Ventilation and Clothes

Y Takahashi,[1,2] K Takano,[1] M Suzuki,[1] S Nagai,[1] M Yokosuka,[1] T Takeshita,[2] A Saito,[3] H Yasueda,[3] T Enomoto[4]

[1] Fabric and Home Care Research Center, Household Products Research Laboratories, Kao Corporation, Wakayama, Japan
[2] Department of Public Health, Wakayama Medical University, Wakayama, Japan
[3] Clinical Research Center, National Hospital Organization Sagamihara National Hospital, Kanagawa, Japan
[4] Department of Otolaryngology, Japanese Red Cross Society, Wakayama Medical Center, Wakayama, Japan

Abstract

Background: The route by which pollen enters dwellings has not been clarified.
Objective: To evaluate the amount of pollen entering dwellings by ventilation and adhesion to textile products.
Methods: The amount of pollen clinging to fabrics (clothes, laundry, and futon bedding) out of doors was measured by quantification of Japanese cedar pollen antigen Cry j 1. The effect of air ventilation on the amount of pollen indoors was also investigated using several neighboring unoccupied apartments with an identical layout while controlling the ventilation conditions.
Results: The amount of pollen adhering to futons was especially high. More than half of the pollen on futons or laundry remained on the surface, even after being brushed off by hand or shaken off. Vacuuming laundry and futons after airing out would be an effective way to decrease the amount of indoor pollen. A large amount of pollen entered dwellings through air ducts when the windows were closed and the ventilation fans working. Since most pollen that entered by ventilation remained near the windows, cleaning carefully and frequently near windows could reduce the amount of pollen indoors.
Conclusions: To decrease the amount of pollen indoors, special attention must be paid to textile products and ventilation systems during the pollen season.

Key words: Ventilation. Pollen. Japanese cedar pollinosis. Self-care. Allergen.

Resumen

Antecedentes: No se conoce la vía por la cual el polen entra en los hogares.
Objetivo: Nuestro objetivo fue evaluar la cantidad de polen que accede en las viviendas mediante los conductos de ventilación y su adhesión a los productos textiles.
Métodos: La cantidad de polen que se adhiere a los tejidos (ropa, colada y colchones) en el exterior se midió mediante cuantificación del antígeno del polen de cedro japonés Cry j 1. El efecto de la ventilación sobre la cantidad de polen presente en el interior de los hogares, se investigó analizando diversas viviendas vecinas desocupadas, que tenían una distribución idéntica y controlando en éstas las condiciones de ventilación.
Resultados: La cantidad de polen que se adhiere a los colchones fue especialmente elevada. Más de la mitad del polen de los colchones o de la colada permanece en la superficie, incluso después de haber sido cepillada a mano o sacudida. Pasar el aspirador por la ropa y los colchones después de haber sido aireados, puede ser un mecanismo efectivo por disminuir la cantidad de polen de interior. Por otro lado, una elevada cantidad de polen se introduce en las viviendas, a través de los conductos del aire, mientras las ventanas estaban cerradas y los ventiladores en funcionamiento.
Ya que la mayoría de polen que entraba a través de la ventilación, se aloja cerca de las ventanas, la limpieza minuciosa y frecuente alrededor de las ventanas, puede reducir la cantidad de polen que entra en el interior de las viviendas.
Conclusiones: Para disminuir la cantidad de polen en el interior debe ponerse una atención especial en los tejidos y en los sistemas de ventilación durante la estación polínica.

Palabras clave: Ventilación. Polen. Polinosis del cedro japonés. Cuidado de la salud personal. Alérgeno

Introduction

The prevalence of allergic diseases is increasing around the world [1,2]. In Japan, pollinosis is one of the most common seasonal allergic diseases, and the frequency of Japanese cedar pollinosis is reported to be about 13% [3]. Pollinosis is an immunological disease involving type I hypersensitivity reaction to pollen. Several therapies have been investigated, including immunotherapy, pharmacotherapy, and surgical treatment [4,5]. However, the elimination and avoidance of pollen allergens remain the primary objectives in self-care of pollinosis [6,7]. The Guidelines for treatment of nasal allergy - Perennial Rhinitis and Pollinosis [8] recommend that windows remain closed or that goggles and facemasks are worn during the pollination season. However, in a survey of patients with pollinosis [9], the measures to avoid pollen were often not taken; only 26.6% of patients wore a face mask, 8.4% avoided going outdoors, 6.2% avoided airing out futon bedding or laundry, and 1.0% closed windows and doors.

In many cases, emphasis is placed on avoiding exposure to pollen outdoors, and various kinds of facemasks and goggles are available to prevent pollen inhalation [10]. However, indoor self-care is also important, and it has been reported that a considerable amount of pollen remains indoors, even after the pollen season has ended [11], and nasal inflammation can continue until these levels decrease to 30 counts/m^2 or less [12]. Hence it is important to decrease the amount of indoor pollen and provide better information on the routes of entry.

In the present study, we analyzed textile products and ventilation systems as routes of entry for pollen.

Method

We investigated Japanese cedar pollen (JCP) as an example of a general airborne allergen. JCP, one of the major aeroallergens in Japan, is 30 µm in diameter and globe-shaped with a short papilla. We examined 4 routes of entry: clothes, laundry, futons (Japanese bedding), and ventilation. In the first 3, pollen adheres to the textile surface out of doors, although this process is not yet completely understood. The amount of Cry j 1, a major allergen of cedar pollen, was measured using the enzyme-linked immunosorbent assay (ELISA). The fourth route—air ventilation—was assessed by analyzing the amount and distribution of indoor pollen using Vaseline-coated glass slides. Although airborne pollen is generally collected by volumetric methods, we used the gravimetric method to study the distribution of pollen on the floor.

Clothes

Two people wearing the same clothes, a woolen coat and woolen trousers, spent the day outdoors involved in everyday activities from 8 am to 4 pm on March 9, 2005 in Tokyo. When they returned, their coats and trousers were cleaned using a vacuum cleaner (CV-CF4, 540W, Hitachi Ltd., Tokyo, Japan) to collect the JCP in a paper bag in a clean room. The content of the paper bag was extracted using phosphate-buffered saline, and the amount of Cry j 1 in the extract was measured using ELISA.

Laundry

Towels and t-shirts were hung out to investigate the amount of pollen adhering to laundry. On March 9, 2005, from 10 am to 4 pm, 4 towels (cotton, 30 cm × 70 cm) and 4 t-shirts (cotton, extra-large size for men) were washed and hung out to dry on the roof of an 8-story building in Tokyo. Two sets of towels and t-shirts were carried carefully into a clean room, and the other 2 sets were shaken off outside before being taken into the room. Each item was then vacuumed and the amount of Cry j 1 was quantified using ELISA.

Futons

Futons were hung out to investigate the amount of pollen adhering to the surface. On March 9, 2005, from 10 am to 4 pm, 2 pairs of futons with cotton covers (single size, 100 cm × 200 cm) were hung out on the roof of an 8-story building in Tokyo. Futons were folded in half and then hung on a laundry pole. One was carried carefully into a clean room, and the other was brushed off by hand before being taken into the clean room. Each futon was then vacuumed and the amount of Cry j 1 was quantified using ELISA.

Ventilation

This work was performed using 6 unoccupied neighboring apartments with an identical layout under controlled ventilation conditions. A fourth-floor apartment in Funabashi city, Chiba Prefecture, was used for the ventilation test on March 8 and 10, 2005. The experiment ran from 9 am to 5 pm on each day (total experimental time of 16 hours). In the interval, all windows were closed and all ventilation holes were sealed. The experimental area is shown as a boxed area with a heavy solid line in the layout drawing (Figure 1). Every apartment had 2 ventilation fans in the kitchen and the bathroom (not shown in Figure 1), and ventilation holes near the windows in the living room and dining room (this is typical in Japanese apartments). Vaseline-coated glass slides were placed at grid points on the floor of the experimental area (Figure 1). The slides were stained with gentian violet and the pollen counted under an optical microscope. The ventilation conditions are shown in Table 1.

Cry j 1 assay

The amount of Cry j 1 in extracted samples was determined using a highly sensitive Cry j 1 assay kit (LCD Laboratory, Osaka, Japan) [13].

The wells of 96-well polystyrene micro plates (Nunc, Tokyo, Japan) were coated with 100 µL of anti-Cry j 1 antibody (0.2 µg/mL monoclonal antibody; LCD Laboratory) for 2 hours at 37°C and washed 5 times with 300 µL of 0.01 M PBS (pH 7.4) containing 0.5% Tween 20. After being blocked with 300 µL of 0.01 M phosphate-buffered saline containing 2% bovine serum albumin for 2 hours at 37°C, the wells were washed again, and a 100-µL aliquot of each sample and standard was added to the wells and incubated for

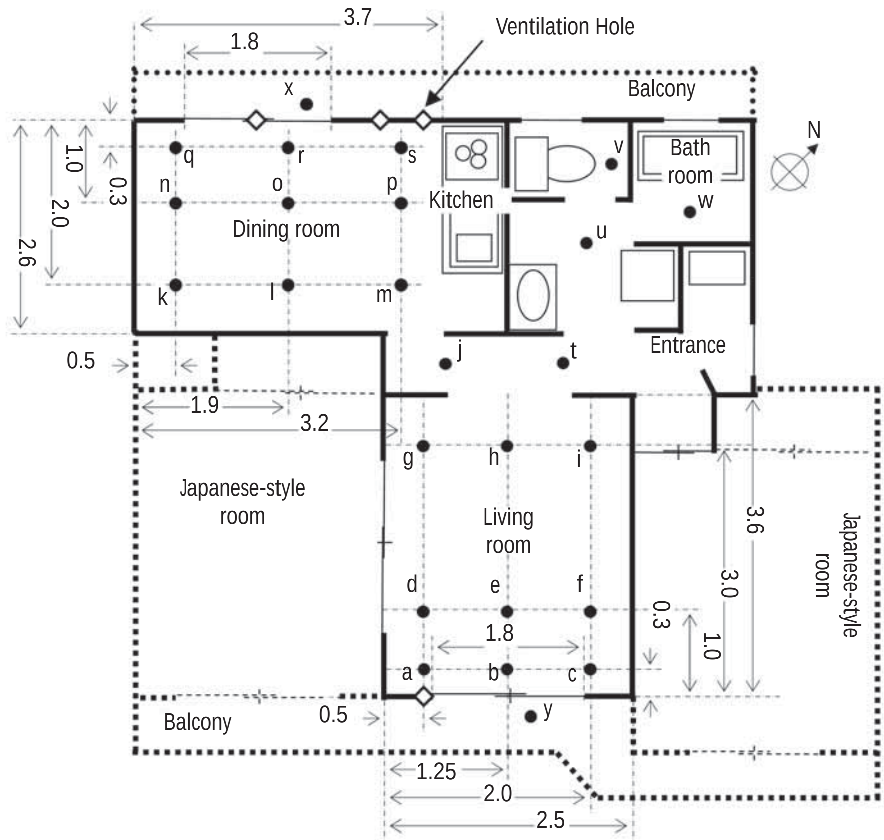

Figure 1. Arrangement of the sampling points (a to y, solid circle) in the room layout. The midair squares (4 points, near the windows) represent ventilation holes. The unit of length is the meter.

Table 1. Ventilation Conditions

Conditions		A	B	C	D	E	F
Windows		Fully open	Fully open	10 cm open	Shut	Shut	Shut
Curtains		Open	Closed	Closed	None	None	None
Ventilation fans	Bathroom	Off	Off	Off	On	On	On
	Kitchen	Off	Off	Off	Off	On	On
Ventilation holes		Sealed	Sealed	Sealed	Open	Open	Closed

10 hours at 25°C. The standard sample added in the LCD kit was prepared as reported elsewhere [14]. After a third wash, a biotinylated anti-Cry j 1 antibody (Rabbit polyclonal antibody, LCD Laboratory, Osaka, Japan) was added to the wells and incubated for 3 hours at 37°C. After washing 3 times, 100 µL of conjugated streptavidin-ß-galactosidase was added to the wells and the samples were incubated for 1 hour at 37°C. After washing 4 times, 100 µL of 10 mmol/L o-nitrophenyl-ß-D-galactopyranoside was added to the samples to develop a color reaction for 10 minutes at 37°C. As the final step, the reaction was terminated by the addition of 1.5 M of sodium carbonate and, after stirring, the absorbance of the samples was measured at 415 nm using a microplate reader.

The amount of Cry j 1 was converted to the number of

JCP by equating 6 pg of Cry j 1 with 1 JCP. The value 6 pg in a pollen grain was confirmed by examination; Japanese cedar pollen was counted under the microscope, and Cry j 1 quantified using ELISA. From the number of pollen and amount of Cry j 1, the value of 6 pg Cry j 1 in a pollen grain was determined.

Statistical Analysis

Statistical analysis was performed using a 1-way ANOVA. If a significant difference was detected, the individual group difference was determined using a multiple Wilcoxon matched-pair signed-rank test with a Bonferroni adjustment. A *P* value below .05 was considered statistically significant.

Results

Clothes

The average amount of JCP adhering to 2 of the woolen coats was 9.4 counts/cm^2/h and to the 2 pairs of woolen trousers 14.5 counts/cm^2/h.

Laundry

The average amount of JCP was 18.9 counts/cm^2/h for the towels and 10.2 counts/cm^2/h for the t-shirts. For the towels and t-shirts that were shaken off before being brought into the clean room, the average amount of JCP decreased to 11.1 counts/cm^2/h and 3.9 counts/cm^2/h, respectively.

Futons

The amount of JCP on the outer side of the futon was 14.6 counts/cm^2/h, and the amount of JCP on the inner side was 6.1 counts/cm^2/h (average 10.3 counts/cm^2/h, with 71% of the total amount of pollen was found on the outer side of the futon). When the outer side of the other futon was brushed off by hand before being brought inside, the amount of JCP on the outer side and inner side decreased to 10.9 counts/cm^2/h and 6.0 counts/cm^2/h, that is, the average amount of JCP on the futon decreased to 8.4 counts/cm^2/h.

These results for the amount of pollen adhering to clothes, laundry and futons are shown in Figure 2A, and the amount of pollen corresponding to each product is shown in Figure 2B.

Ventilation

The amount of pollen entering the balcony areas of the 6 apartments proved to be nearly the same during the experiment; the amount of pollen was 24-29 counts/cm^2/h at point x shown in Figure 1, and 19-22 counts/cm^2/h at point y. The results for conditions A, B, and C are shown in Table 2. Under condition A (windows fully open with curtains open), pollen distribution followed the airflow path in the apartment. The average amount of pollen found on the floor was 4.8 counts/cm^2/h. The amount of pollen entering the apartment under this condition was 24% of that observed on the balcony. Under condition B (windows fully open with curtains closed), a large quantity of pollen was distributed near the windows (points a, b, and c and q, r, and s), and the amount of JCP gradually decreased the further the distance from the windows. The amount of pollen entering the apartment was 66% of that observed under condition A. Under condition C (windows 10 cm open with curtains closed), the distribution of pollen was similar to that observed under condition B, and the amount of pollen in the apartment was 24% of that observed under condition B. The amount of pollen under conditions A, B, and C was analyzed using the Friedman test, and the *P* value was

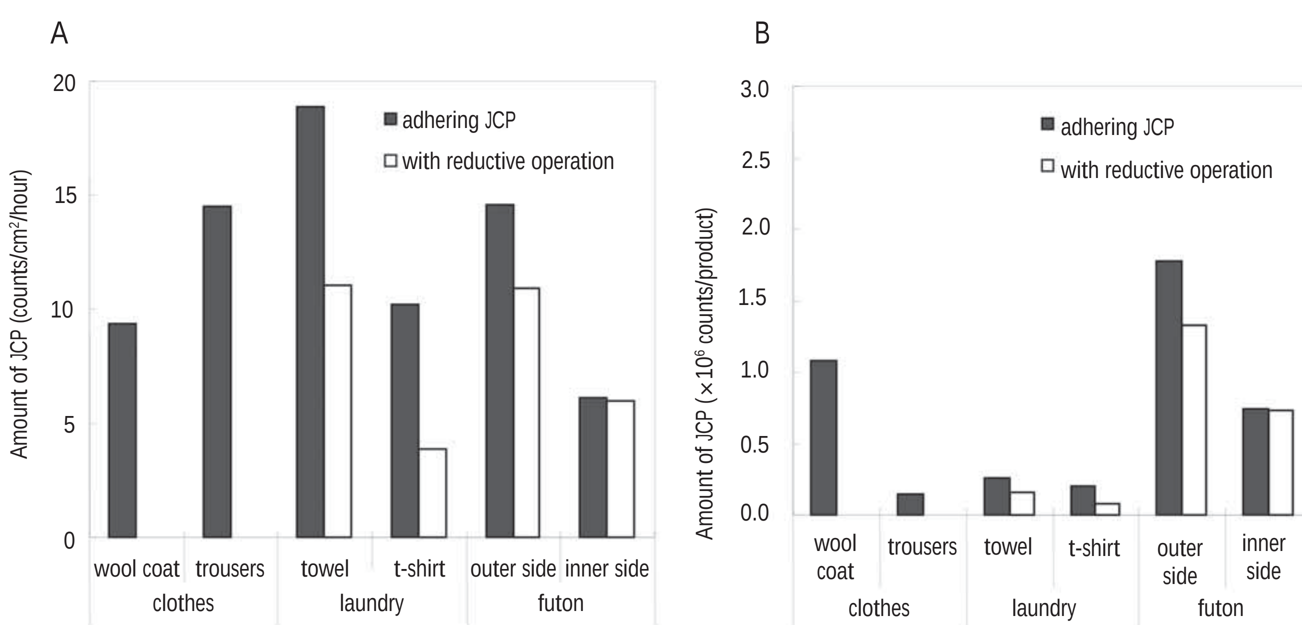

Figure 2. The amount of Japanese cedar pollen adhering to textile products; A, JCP in counts per cm^2 per hour; B, JCP $\times 10^6$ counts per product

Table 2. Number of Japanese Cedar Pollen on Vaseline-Coated Glass Slides (counts/cm^2/h) Under Ventilation Conditions A, B, and C

	a	b	c	d	e	f	g	h	i	j	k	l	m	n
A	9.59	6.32	5.41	6.09	5.30	5.30	9.48	5.64	6.54	6.54	4.51	4.85	6.66	4.06
B	6.94	10.69	10.36	5.67	6.60	6.05	2.54	3.24	2.88	1.67	1.59	1.15	1.23	2.93
C	0.60	2.95	2.73	0.84	1.45	2.15	0.28	0.86	1.19	0.62	0.46	0.52	0.20	0.80

	o	p	q	r	s	t	u	v	w	Average	x	y
A	5.53	5.30	5.41	6.09	5.19	3.16	1.58	0.00	0.00	5.15	28.80	20.00
B	2.14	1.75	2.57	4.10	2.85	0.44	0.52	0.04	0.00	3.39	25.10	19.30
C	0.50	0.08	0.88	1.25	0.22	0.22	0.20	0.02	0.00	0.83	23.70	21.50

Table 3. Number of Japanese Cedar Pollen (counts/cm^2/h) on Vaseline-Coated Glass Slides (a to y) Under Ventilation Conditions D, E, an d F

	a	b	c	d	e	f	g	h	i	j	k	l	m	n
D	1.77	1.17	1.31	0.36	0.28	0.54	0.08	0.04	0.42	0.04	0.04	0.14	0.12	0.16
E	1.95	0.36	1.04	0.70	0.30	0.44	0.20	0.18	0.10	0.18	0.44	0.40	0.12	0.62
F	0.20	0.50	1.10	0.40	0.10	1.00	0.10	0.10	0.10	0.00	0.40	0.30	0.10	0.70

	o	p	q	r	s	t	u	v	w	Average	x	y
D	0.28	0.36	0.10	0.40	0.82	0.14	0.02	0.06	0.06	0.38	25.70	21.60
E	0.54	0.30	1.17	0.56	0.28	0.04	0.06	0.08	0.02	0.44	28.40	19.10
F	0.30	0.30	0.80	0.60	1.20	0.10	0.00	0.20	0.10	0.38	24.70	19.60

calculated to be $<.001$. The Wilcoxon test showed that there were significant differences between the 3 conditions.

The results of conditions D, E, and F are shown in Table 3. Even under these conditions, where all the windows were closed, the amount of pollen entering each apartment was not zero, but less than that observed in condition C. In these conditions, most of the pollen was observed near the ventilation holes and windows, and the amount of pollen tended to decrease when the distance from these points increased. Under condition E (ventilation fans in the bathroom and kitchen working with ventilation holes open and windows closed), the amount of pollen was 116% of that observed under condition D (ventilation fan in bathroom working with ventilation holes open and windows closed). Under condition F (ventilation fans in the bathroom and kitchen working with ventilation holes shut and windows closed), almost the same amount of pollen was observed as under condition E.

Airborne Pollen

In Japan, the automatic airborne pollen observation system is operated by the Ministry of the Environment [15]. The system is based on a modified laser particle counter (KH-3000, Yamato Manufacturing Co. Ltd, Kanagawa, Japan), and the pollen count is highly correlated with a conventional sampler ($R > 0.8$) [16]. According to the observation system, the average amount of JCP during the experiments with textile products and ventilation was reported to be 267 counts/m^3/h and 164 counts/m^3/h, respectively.

Discussion

The average amount of pollen on laundry was 18.9 counts/cm^2/h on the towel and 10.2 counts/cm^2/h on the t-shirt. Adhesion varied according to the surface texture of the fabric. The surface of the t-shirt was flatter than that of the towel; therefore, less pollen adhered to the t-shirt than to the towel. The amount of pollen found on 3 of the towels was equal to that of the pollen found on a woolen coat. The Guidelines for treatment of nasal allergy - Perennial Rhinitis and Pollinosis recommend shaking pollen from clothes before going indoors; however, laundry should also be shaken out before being taken indoors to decrease the amount of pollen adhering to the surface. The amount of pollen on futons was especially high. Although the futons were folded over a clothesline pole, there was a considerable amount of pollen even on the inner sides, which were shaded from falling pollen and not exposed to fresh air. The total amount of pollen on the futon was 2.5×10^6 counts, and 80% remained even after the outer side was brushed off by hand. Considering the amount of pollen adhering to futons and the fact that futons are close to our faces during sleep, they should be vacuumed after airing out. A considerable amount of pollen was easily detached from textile products and scattered indoors if they were brought indoors without being brushed or shaken off. Therefore, they should receive special attention during the pollen season in order to decrease the amount of pollen coming indoors with textile products.

The amount of pollen coming into dwellings by ventilation varied according to the conditions of the windows. When the windows and the curtains were both opened, the amount of pollen in the dwelling was 1.5 times higher than when the curtains were closed (conditions A and B in Table 1). When the windows were opened slightly, the amount of pollen decreased to about 25% (conditions B and C). If windows are opened for ventilation during the pollen season, then leaving only a small space open or closing curtains would decrease the amount of pollen.

Surprisingly, some pollen came into the apartment by airflow, even through closed windows or ventilation holes when ventilation fans were working (conditions D, E, and F). In condition F, it was confirmed that air flowed from the ventilation holes into the room even though the dampers were closed. When the ventilation fan in the kitchen or the bathroom was working, it created negative pressure in the room. Therefore, some pollen was entering through the gaps in the ventilation holes, even if the dampers were shut. As for pollen distribution in rooms, the amount of pollen decreased, the further the distance from the ventilation holes and windows. Since most of the pollen that entered was found near the ventilation holes and the windows, cleaning these areas carefully and frequently could be an effective way of reducing the amount of indoor pollen.

The total amount of pollen coming indoors per day was estimated by ventilation for an hour with the windows opened 10 cm and for 23 hours with the windows shut while using a ventilation fan in the bathroom to represent a typical daily pattern of life in the dwelling (1 hour of condition C and 23 hours of condition D). The average amount of pollen in the total floor area was calculated to be 9.6 counts/cm^2/d, and this pollen density corresponded to 2.9×10^6 counts/d in our experimental area (30 m^2). This amount was similar to that observed on textile products, although a larger amount of airborne pollen was observed in the experiment with textile products, thus stressing the importance of textile products and ventilation as routes of entry during the pollen season. Under this ventilation condition (1 hour of condition C and 23 hours of condition D), the amount of pollen entering when windows were closed (23 hours under condition D) accounted for 90% of the total amount. Although the World Allergy Organization Guidelines for the Prevention of Allergy and Allergic Asthma [17] recommend keeping windows closed, long-term ventilation should also be taken into consideration, even when windows are closed. We also found that 75% of all pollen coming indoors was within 1.5 m of the windows. Therefore, sweeping carefully near windows or installing filters for ventilation holes may prove effective.

In summary, we show how pollen can enter dwellings on the surface of textile products and in ventilation channels. The amount of pollen entering by ventilation was especially high, thus demonstrating the importance of countermeasures with this channel. When windows are opened for air ventilation, closing curtains is an effective way to decrease pollen indoors. Even if windows are closed, it is important to deal with pollen that enters through ventilation holes. Since most of the pollen that enters by ventilation is situated near windows, frequent and careful cleaning in this area would be an effective way of decreasing the amount of pollen indoors. As for textile products, a large of amount of pollen enters the dwelling on the surface. During the pollen season, they should be brushed off before being taken indoors. These recommendations will help to decrease the amount of indoor pollen and improve self-care for pollinosis.

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References

1. Wüthrich B. Epidemiology of the allergic diseases: Are they really on the increase? Int Arch Allergy Appl Immunol. 1989;90:3-10.
2. Sibbald B, Strachan DP. Epidemiology of rhinitis. In Busse NW, Holgate ST (editors): Asthma and Rhinitis. Boston: Blackwell Scientific Publications; 1995. p. 32-43.
3. Okuda M. Epidemiology of Japanese cedar pollinosis throughout Japan. Ann Allergy Asthma Immunol. 2003;91:288-96.
4. Rosenwasser LJ. Treatment of allergic rhinitis. Am J Med. 2002;113:17S-24S.
5. Corren J. Allergic rhinitis: Treating the adult. J Allergy Clin Immunol. 2000;105:S610-15.
6. Platts-Mills TA, Tovey ER, Mitchel EB, Moszoro H, Nock P, Wilkins SR. Reduction of bronchial hyperactivity during prolonged allergen avoidance. Lancet 1982;2:675-8.
7. Boner AL, Peroni D, Sette L, Valletta EA, Piacentini G. Effects of allergen exposure-avoidance on inflammation in asthmatic children. Allergy 1993;48:119-23.
8. Baba K, Konno A, Takenaka H. Treatments. In: Okuda M, editor. Guidelines for treatment of nasal allergy - Perennial Rhinitis and Pollinosis. Tokyo: Life Science Publishing; 2002. p. 30-47.
9. Dake Y, Enomoto T, Funakoshi H, Sakaguchi K, Fujiki Y, Kakiuchi H, Kato Y, Okuno Y, Ikeda M. Preventive care for Japanese cedar pollinosis. Oto-Rhino-Laryngology, Tokyo. 2003;46:51-6.
10. Platts-Mills TA. Allergen avoidance. J Allergy Clin Immunol. 2004;113:388-91.
11. B. Fahlbusch, D. Hornung, J. Heinrich, H.-M. Dahse, L. Jäger. Quantification of group 5 grass pollen allergens in house dust. Clin Exp Allergy. 2000;30:1646-52.
12. Enomoto T, Onishi S, Sogo H, Dake Y, Ikeda H, Funakoshi H, Shibano A, Sakoda T. Japanese cedar pollen in floating indoor house dust after a pollinating season. Allergology International. 2004;53:279-85.
13. Enomoto T, Onishi S, Yasueda H, Dake Y, Sogo H, Fujiwara S, Fujiki Y, Seno S, Ide T. The evaluation and application of high sensitive Cry j 1 assay. Jpn J Palynol. 2000;46:9-16.
14. Yasueda H, Yui Y, Shimizu T, Shida T. Isolation and partial characterization of the major allergen from Japanese cedar (Cryptomeria japonica) pollen. J Allergy Clin Immunol. 1983;71:77-86.
15. WWW site of the airborne pollen observation system by Ministry of the Environment: http://kafun.taiki.go.jp/
16. Delaunay JJ, Sasajima H, Okamoto Y, Yokota M. Side-by-side comparison of automatic pollen counters for use in pollen information systems. Ann Allergy Asthma Immunol. 2007;98:553-8.
17. Johansson SGO, Haahtela T. World Allergy Organization Guidelines for Prevention of Allergy and Allergic Asthma. Int Arch Allergy Immunol. 2004;135:83-92.

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Yusuke Takahashi

Fabric & Home Care Research Center,
Household Products Research Laboratories,
Kao Corporation
1334, Minato, Wakayama-city
Wakayama 640-8580, Japan
E-mail: takahashi.yuusuke2@kao.co.jp