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Original Article

Aeroallergen Sensitization Status in South Korea From 2018 to 2021

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Objectives. Studies on the aeroallergen sensitization status of South Koreans based on large-scale data are lacking.

Methods. We analyzed data from 368,156 multiple allergosorbent tests collected by a domestic medical diagnosis company from 3,735 hospitals nationwide from 2018 to 2021. We additionally collected sex, age, and regional data. If the level of an aeroallergen was 0.35 IU/mL or more, the test result for that aeroallergen was defined as positive, and positive cases were defined as those where one aeroallergen was positive. The positive ratio (PR) for aeroallergens was calculated using positive cases.

Results. In total, 347,996 cases were analyzed, excluding cases with missing data. The percentage of positive cases was 56.7%, which was highest in adolescents (74.1%) and lowest in the elderly (47.0%). All four types of mites had high PRs (0.382–0.655), and mold had low PRs (0.023–0.058). Among pollens, the PRs of grasses were generally high (more than 0.14), followed by weeds (approximately 0.10), and the PRs of woods was less than 0.1. For animals, cats and dogs had the highest PRs, at 0.231 and 0.183, respectively. The value for cockroaches was also high, at 0.211. The PRs of indoor aeroallergens, such as mites, molds, and animals, were high in adolescents, and those of pollen and cockroaches were high in the elderly. In Jeju, the PR of Japanese cedars was extremely high (0.222).

Conclusion. Koreans were found to be sensitized to a wide variety of aeroallergens. There were significant differences in sensitization patterns according to age and region.

Keywords. *Aeroallergen; Sensitization; Multiple Allergosorbent Tests; Korea*

INTRODUCTION

Allergic rhinitis, allergic conjunctivitis, and allergic asthma are representative diseases caused by aeroallergens that have a high prevalence worldwide [1,2]. In South Korea (hereafter, Korea), the prevalence of respiratory allergic diseases is gradually increasing [3,4]. Allergic diseases are caused by a combination of genetic and environmental factors [2,5]. Considering that the number of multicultural households in Korea was less than 2% in 2020 [6], this increase is likely due to environmental factors rather than a change in genetic factors. Air pollution and the westernization of diet and lifestyle are typical environmental factors [5]. With the proliferation of new plant species due to climate warming and the introduction of various pets, the types of allergens causing respiratory allergies are estimated to become very diverse [7,8].

Many studies have been conducted on the status of aeroallergen sensitization in Koreans [9-20]. However, many of these studies are old, and it is difficult to consider them representative of the national situation as only a limited number of aeroallergens were investigated, or relatively few patients were enrolled at a single institution. Furthermore, the recently used aeroallergen panel is somewhat different from that determined in 2001 [21].

In this study, data regarding more than 360,000 multiple allergosorbent tests (MASTs) stored by a domestic medical diagnosis company over the past 3 years were analyzed. These data

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were collected all over the country, and the MAST kit used for the test was also produced in 2017, enabling the detection of new aeroallergens. In this study, we investigated the status of aeroallergen sensitization in Koreans.

MATERIALS AND METHODS

Data collection

We analyzed the data for 368,156 MASTs stored by a domestic medical diagnosis company (Seegene, Seoul, Korea). The company received blood samples from 3,735 hospitals nationwide through 122 branches and performed MAST at four centers from January 2, 2018, to June 30, 2021. The data included the date of sampling, sex, age, branch name where the blood sample was collected, name and address of the hospital that sent the blood sample, and levels of total immunoglobulin E (IgE) and 49 aeroallergens. However, medical records, such as the patient's symptoms, diagnosis, and nasal findings, could not be obtained. Patients having an age of 0 or over 90 years were excluded because the possibility of input errors was high; cases with missing data were also excluded.

MAST

PROTIA Allergy-Q 96M panel (ProteomeTech Inc., Seoul, Korea) was used to measure the level of specific IgE against the following 49 aeroallergens. Mite: house dust, *Dermatophagoides pteronyssinus* (DP), *Dermatophagoides farina (DF)*, *Acarus siro*, and *Tyrophagus putrescentiae*; Mold: *Penicillium notatum*, *Cladosporium herbarum*, *Aspergillus fumigatus*, *Candida albicans*, and *Alternaria alternate*; Grass: Bermuda grass, sweet vernal grass, orchard grass, reed, bent grass, timothy grass, and cultivated rye; Wood: alder, birch, hazel, oak, olive, maple leaf sycamore, willow, cottonwood, white ash, white pine, Japanese cedar, and acacia; Weed: ragweed, mugwort, ox-eye daisy, dandelion, plantain, Russian thistle, goldenrod, pigweed, and Japanese hop; and Animal/Insect: cat, horse, dog, guinea pig, mouse, rat, sheep, rabbit, hamster, and cockroach. Depending on the level of IgE, the results are graded as belonging to 0 to 6 classes: 0 class (0.00–0.34 IU/mL), 1 class (0.35–0.69 IU/mL), 2 class (0.70–3.49 IU/mL), 3 class (3.50–17.49 IU/mL), 4 class (17.50–49.99 IU/mL), 5 class (50.00–99.99 IU/mL), 6 class (≥100 IU/mL). We defined class 1 or higher as positive.

Data analysis

If an aeroallergen was positive, the case was defined as being positive. The positive ratio (PR) of individual aeroallergens was calculated only for positive cases. Additionally, the PR was calculated based on age and region. Age groups were classified as children (1–12 years old), adolescents (13–18 years old), adults (19–59 years old), and elderly (over 60 years old). Nine regions were demarcated (Seoul-Gyeonggi, Gangwon, Chungnam, Chungbuk, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, and Jeju) according to the location of the branch where blood sampling was collected. No special statistical inference was performed, and calculations were performed using Python (version 3.10.1; Python Software Foundation, Wilmington, DE, USA) and Excel (Microsoft Excel version 2016, Redmond, WA, USA).

This study was exempted from ethical review by the Konkuk University Hospital Institutional Review Board (No. KUMC 2021-03-039) and Seegene Institutional Review Board (No. SMF-IRB-2021-009) because it was an observational study conducted using data collected in the past, and all personal information of the participants, other than age and gender, was removed.

HIGHLIGHTS

- We analyzed data from 347,996 multiple allergosorbent tests to evaluate the sensitization to aeroallergens in South Koreans.
- South Koreans were sensitized to a wide variety of aeroallergens.
- The patterns of this sensitization were very different by age and region.
- Poly-sensitization was common in adolescents.

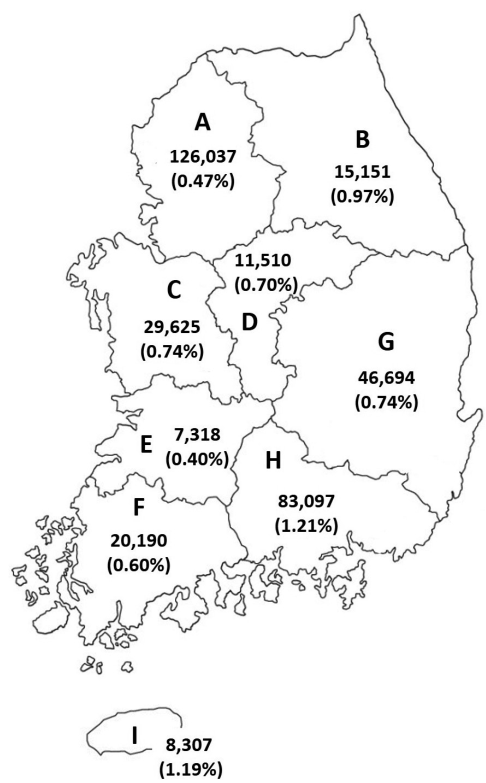

Fig. 1. Regional distribution of cases. A: Seoul-Gyeonggi, B: Gangwon, C: Chungnam, D: Chungbuk, E: Jeonbuk, F: Jeonnam, G: Gyeongbuk, H: Gyeongnam, I: Jeju. The value in the parenthesis denotes the percentage of cases relative to the local population.

RESULTS

The total number of cases was 368,156; from these, 347,996 cases were analyzed, with the exclusion of 18,889 cases corresponding to those aged 0 or ≥90 years and 1,271 cases with missing data. This figure is equivalent to approximately 0.66% of the total population of Korea in 2020, and the regional distribution varied from 0.40% to 1.21% (Fig. 1). The study included 159,561 male patients (45.9%) and 188,433 female patients

Table 1. Age distribution of cases

Age	Total cases	Positive case[a]
Children (1–12 yr)	100,226	52,203 (52.1)
Adolescents (13–18 yr)	19,614	14,527 (74.1)
Adults (19–59 yr)	179,041	107,364 (60.0)
Elderly (≥60 yr)	49,115	23,071 (47.0)
Total	347,996	197,165 (56.7)

[a]The value in the parenthesis denotes the percentage of positive cases relative to total cases.

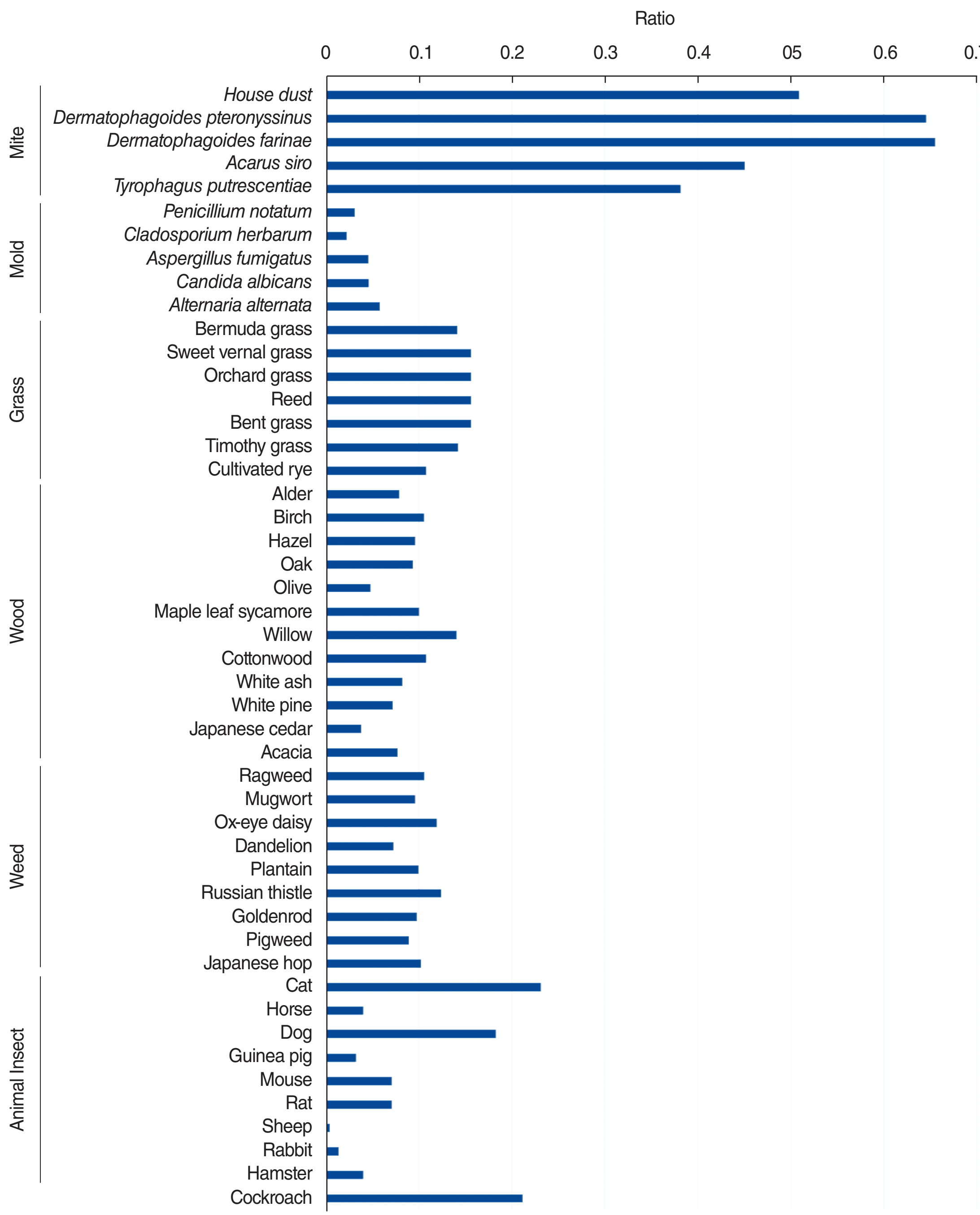

Fig. 2. Positive ratios of aeroallergens.

(54.1%). The distribution of cases by age groups is presented in Table 1. The percentage of positive cases relative to total cases was 56.7%; this percentage was highest in adolescents (74.1%) and lowest in the elderly (47.0%).

PR of aeroallergens

Fig. 2 shows the PR of aeroallergens only for positive cases. The PRs of DP and DF were overwhelmingly high, at 0.645 and 0.655, respectively. The other two types of mites, *A. siro* and *T. putrescentiae*, also had high PRs, at 0.450 and 0.382, respectively. Among molds, the PR of *A. alternata* was the highest at 0.058, and that for all other molds was less than 0.05. For grasses, most PRs were above 0.14; however, for trees, only willow had a PR as high as 0.141, while the others had PRs ranging from 0.035 to 0.108. The PRs for weeds were evenly distributed from 0.073 to 0.124. Among animals, cats and dogs had the highest PRs, at 0.231 and 0.183, respectively. The PR for cockroaches was also high, at 0.211. The PR rankings were in the following order, from highest to lowest: DF, DP, house dust, *A. siro*, *T. putrescentiae*, cats, cockroaches, dogs, sweet vernal grass, orchard grass, reeds, and bent grass, all of which were over 0.15.

Ratios according to the number of the positive aeroallergen types

When aeroallergens were classified into six types (mites, molds, grasses, trees, weeds, and animals/insects), the ratio for only one type of positive aeroallergen was 0.44. As the number of types increased, the ratio decreased exponentially (Fig. 3). On average, the number of types of positive aeroallergens was 2.07; the highest average was found in adolescents (2.31), and the lowest average was 2.00 in children; furthermore, the average number of types of positive aeroallergens was 2.06 in adults and 2.11 in the elderly.

PRs of aeroallergens by age

The PR of each aeroallergen also varied according to age. If a significant difference was defined as more than 40% above or below the mean, the PRs of molds were low in children but high in adolescents. In the elderly, the PRs of many types of grass, trees, and weeds were high, whereas the PRs of animals were low. In adolescents, the PRs for dogs and cats were high, and in children, the PR for horses was high. The elderly had a high PR for cockroaches, unlike children, who had a low PR. These results are presented in Table 2.

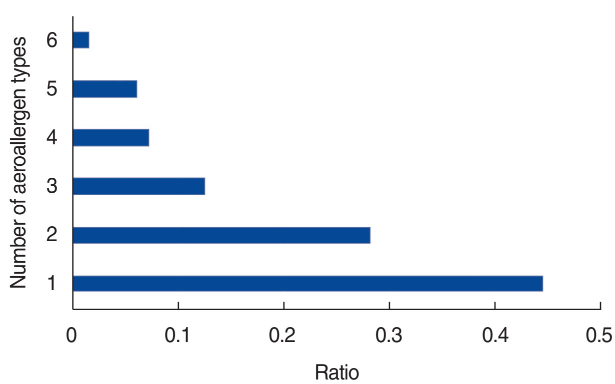

Fig. 3. Percentages of patients according to number of positive aeroallergen types.

PRs of allergens by region

Indoor aeroallergens, such as mites and molds, showed no significant differences by region. However, differences were observed for plants, particularly trees. The PRs of several kinds of trees were high in Gangwon, Jeonnam, and Gyeongbuk. For Jeju, the PRs for all trees and weeds were low, but the PR of Japanese cedar was extremely high (0.222), 5.8 times higher than the national average. The results are presented in Table 3.

DISCUSSION

The rates and types of common aeroallergen sensitization vary widely across countries, and studies conducted in the same country have reported different results [1,2,22]. Studies on sensitization to aeroallergens in Koreans have also shown very different results depending on the test method, type of aeroallergen, region, and subject selection (Table 4) [9-20]. DP and DF showed an overwhelmingly high sensitization rate compared to other antigens, but the reported frequency of sensitization to other aeroallergens had varied from study to study. Common causes include cat, dog, birch, alder, oak, mugwort, and cockroach. However, it was difficult to understand changes in the prevalence of aeroallergens over time by comparing these studies. One study found that the sensitization rate to tree pollen such as oak, birch, alder, and pine increased by 2010 compared to the 1980s, while sensitization to weed and grass pollens decreased. However, DP and DF did not significantly change, and sensitization to dogs and cockroaches slightly decreased [23].

A skin prick test or a specific IgE measurement was performed to identify the causative aeroallergen [5,24]. Although the skin prick test is highly sensitive, it requires specialized personnel and the results are affected by several factors. The ImmunoCAP (ThermoFisher Scientific, Waltham, MA, US) and MAST systems were used for specific IgE measurements [24]. They are not affected by medication, have high specificity, and provide objective results. Although the ImmunoCAP system can quantitatively measure IgE levels for individual allergens, it is expensive and difficult to test multiple allergens simultaneously [5]. In contrast, MAST is the most useful method for studying sensitization to a large number of allergens in a large number of people because it can test more than 60 allergens simultaneously and is relatively inexpensive [24]. Previous studies have shown that the MAST is

Table 2. Positive ratios of aeroallergens by age

Variable	All	Age group			
		Children	Adolescent	Adult	Elderly
Mite					
House dust	0.509	0.527	0.654▲	0.511	0.364▼
Dermatophagoides pteronyssinus	0.645	0.614	0.750	0.670	0.532
Dermatophagoides farinae	0.655	0.622	0.748	0.678	0.558
Acarus siro	0.450	0.415	0.579▲	0.465	0.379
Tyrophagus putrescentiae	0.382	0.392	0.520▲▲	0.380	0.274▼
Mold					
Penicillium notatum	0.031	0.016▼▼▼	0.035	0.036	0.040▲
Cladosporium herbarum	0.023	0.014▼▼	0.032▲▲▲	0.024	0.028▲
Aspergillus fumigatus	0.046	0.050	0.074▲▲▲	0.042	0.035▼
Candida albicans	0.046	0.027▼▼▼	0.066▲▲▲	0.045	0.088▲▲▲
Alternaria alternata	0.058	0.086▲▲▲	0.113▲▲▲	0.047	0.009▼▼▼
Grass					
Bermuda grass	0.141	0.142	0.110▼	0.131	0.211▲▲▲
Sweet vernal grass	0.156	0.157	0.131	0.146	0.220▲▲▲
Orchard grass	0.156	0.157	0.131	0.146	0.220▲▲▲
Reed	0.156	0.157	0.131	0.146	0.220▲▲▲
Bent grass	0.156	0.157	0.131	0.146	0.220▲▲▲
Timothy grass	0.142	0.143	0.117	0.133	0.204▲▲▲
Cultivated rye	0.108	0.106	0.084▼	0.102	0.158▲▲▲
Tree					
Alder	0.079	0.092	0.092	0.067	0.098▲
Birch	0.105	0.123	0.158▲▲▲	0.093	0.089
Hazel	0.096	0.123▲	0.106	0.078	0.111
Oak	0.094	0.092	0.104	0.088	0.120▲
Olive	0.048	0.054	0.040	0.041	0.072▲▲▲
Maple leaf sycamore	0.100	0.119	0.085	0.085	0.142▲▲▲
Willow	0.141	0.151	0.122	0.126	0.201▲▲▲
Cottonwood	0.108	0.137▲	0.106	0.089	0.133▲
White ash	0.082	0.093	0.073	0.071	0.117▲▲▲
White pine	0.072	0.092▲	0.065	0.059	0.095▲▲
Japanese cedar	0.038	0.043	0.042	0.034	0.043
Acacia	0.077	0.084	0.057▼	0.068	0.119▲▲▲
Weed					
Ragweed	0.106	0.098	0.081▼	0.102	0.161▲▲▲
Mugwort	0.096	0.094	0.092	0.092	0.119▲
Ox-eye daisy	0.119	0.102	0.113	0.122	0.148▲
Dandelion	0.073	0.069	0.074	0.070	0.093▲
Plantain	0.100	0.107	0.076▼	0.088	0.151▲▲▲
Russian thistle	0.124	0.096▼	0.078▼▼	0.124	0.220▲▲▲
Goldenrod	0.098	0.089	0.094	0.093	0.134▲▲
Pigweed	0.090	0.081	0.062▼▼	0.086	0.147▲▲▲
Japanese hop	0.102	0.095	0.152▲▲▲	0.099	0.104
Animal/Insect					
Cat	0.231	0.242	0.402▲▲▲	0.228	0.112▼▼▼
Horse	0.041	0.074▲▲▲	0.045	0.029▼	0.012▼▼▼
Dog	0.183	0.224▲	0.264▲▲▲	0.172	0.084▼▼▼
Guinea pig	0.033	0.037	0.038	0.034	0.013▼▼▼
Mouse	0.071	0.090▲	0.067	0.074	0.009▼▼▼
Rat	0.071	0.090▲	0.067	0.074	0.009▼▼▼
Sheep	0.005	0.006▲	0.005	0.004	0.004
Rabbit	0.014	0.014	0.017▲	0.014	0.011
Hamster	0.040	0.053▲▲	0.040	0.040	0.008▼▼▼
Cockroach	0.211	0.093▼▼▼	0.202	0.249	0.314▲▲▲

▲, 20% or more of the average; ▲▲, 30% or more; ▲▲▲, 40% or more; ▼, 20% or less of the average; ▼▼, 30% or less; ▼▼▼, 40% or less.

Table 3. Positive ratios of aeroallergens by region

Variable	All	Seoul-Gyeonggi	Gangwon	Chungnam	Chungbuk	Jeonbuk	Jeonnam	Gyeongbuk	Gyeongnam	Jeju
Mite										
House dust	0.509	0.510	0.526	0.511	0.493	0.479	0.502	0.459	0.500	0.603
Dermatophagoides pteronyssinus	0.645	0.647	0.648	0.640	0.632	0.629	0.635	0.589	0.636	0.740
Dermatophagoides farinae	0.655	0.659	0.665	0.653	0.643	0.636	0.638	0.597	0.643	0.731
Acarus siro	0.450	0.448	0.456	0.455	0.434	0.450	0.452	0.402	0.445	0.547▲
Tyrophagus putrescentiae	0.382	0.380	0.397	0.383	0.357	0.373	0.385	0.334	0.379	0.478▲
Mold										
Penicillium notatum	0.031	0.031	0.028	0.029	0.034	0.030	0.030	0.034	0.030	0.035
Cladosporium herbarum	0.023	0.022	0.021	0.023	0.024	0.024	0.022	0.025	0.020	0.027
Aspergillus fumigatus	0.046	0.048	0.041	0.055	0.051	0.046	0.043	0.049	0.035▼	0.042
Candida albicans	0.046	0.043	0.037	0.047	0.056	0.067▲▲▲	0.056	0.051	0.043	0.036▼
Alternaria alternata	0.058	0.064	0.052	0.077▲▲	0.063	0.051	0.062	0.060	0.039▼▼	0.054
Grass										
Bermuda grass	0.141	0.122	0.164	0.148	0.175▲	0.165	0.169	0.185▲▲	0.123	0.105▼
Sweet vernal grass	0.156	0.133	0.173	0.160	0.188	0.188▲	0.198▲	0.195▲	0.139	0.149
Orchard grass	0.156	0.133	0.173	0.160	0.188	0.188▲	0.198▲	0.195▲	0.139	0.149
Reed	0.156	0.133	0.173	0.160	0.188	0.188▲	0.198▲	0.195 ▲	0.139	0.149
Bent grass	0.156	0.133	0.173	0.160	0.188	0.188▲	0.198▲	0.195▲	0.139	0.149
Timothy grass	0.142	0.121	0.160	0.147	0.169	0.171▲	0.179▲	0.182▲	0.125	0.128
Cultivated rye	0.108	0.090	0.114	0.108	0.131▲	0.118▲	0.131▲	0.138▲	0.104	0.097
Tree										
Alder	0.079	0.064	0.095	0.073	0.089	0.070	0.089	0.106▲▲	0.085	0.042▼▼
Birch	0.105	0.094	0.157▲▲▲	0.095	0.101	0.068▼▼	0.099	0.132▲	0.111	0.041▼▼▼
Hazel	0.096	0.081	0.120▲	0.097	0.107	0.091	0.103	0.124▲	0.095	0.061▼▼
Oak	0.094	0.087	0.114▲	0.084	0.105	0.074▼	0.092	0.127▲▲	0.086	0.053▼▼
Olive	0.048	0.041	0.055	0.050	0.060▲	0.050	0.053	0.067▲▲▲	0.043	0.028▼▼
Maple leaf sycamore	0.100	0.083	0.120	0.104	0.127▲	0.117	0.139▲▲	0.136▲▲	0.085	0.064▼▼
Willow	0.141	0.123	0.162	0.143	0.169	0.161	0.181▲	0.178▲	0.126	0.094▼▼
Cottonwood	0.108	0.099	0.145▲▲	0.119	0.137▲	0.111	0.117	0.138▲	0.084▼	0.076▼
White ash	0.082	0.070	0.097	0.083	0.102▲	0.096	0.121▲▲▲	0.107▲	0.070	0.051▼▼
White pine	0.072	0.060	0.089▲	0.073	0.090▲	0.072	0.082	0.101▲▲	0.064	0.054▼
Japanese cedar	0.038	0.023▼▼	0.032	0.028	0.037	0.032	0.065▲▲▲	0.041	0.033	0.222▲▲▲
Acacia	0.077	0.062	0.089	0.080	0.099▲	0.086	0.099▲	0.103▲▲	0.071	0.060▼
Weed										
Ragweed	0.106	0.097	0.123	0.098	0.127	0.103	0.112	0.141▲▲	0.092	0.081▼
Mugwort	0.096	0.093	0.112	0.097	0.113	0.090	0.097	0.116▲	0.082	0.057▼▼
Ox-eye daisy	0.119	0.118	0.137	0.124	0.139	0.142	0.149▲	0.141	0.089▼	0.079▼▼
Dandelion	0.073	0.069	0.087	0.075	0.087	0.068	0.070	0.087	0.064	0.045▼▼
Plantain	0.100	0.084	0.122▲	0.103	0.127▲	0.106	0.114	0.133▲▲	0.091	0.062▼▼

(Continued to the next page)

Table 3. Continued

Variable	All	Seoul-Gyeonggi	Gangwon	Chungnam	Chungbuk	Jeonbuk	Jeonnam	Gyeongbuk	Gyeongnam	Jeju
Russian thistle	0.124	0.105	0.141	0.124	0.163▲▲	0.155▲	0.153▲	0.164▲▲	0.112	0.074▼▼
Goldenrod	0.098	0.091	0.118▲	0.094	0.119▲	0.099	0.106	0.120▲	0.085	0.065▼▼
Pigweed	0.090	0.076	0.106	0.092	0.120▲▲	0.104	0.100	0.122▲▲	0.079	0.059▼▼
Japanese hop	0.102	0.099	0.094	0.116▼	0.139▲▲	0.095	0.108	0.124▲	0.084	0.073▼
Animal/insect										
Cat	0.231	0.246	0.245	0.234	0.222	0.181▼	0.206	0.220	0.215	0.194
Horse	0.041	0.039	0.029▼	0.037	0.034	0.030▼	0.040	0.034	0.051▲	0.031▼
Dog	0.183	0.197	0.190	0.185	0.158	0.150	0.158	0.166	0.176	0.136▼
Guinea pig	0.033	0.033	0.029	0.032	0.028	0.030	0.028	0.030	0.036	0.022▼▼
Mouse	0.071	0.072	0.058	0.064	0.063	0.051▼	0.069	0.062	0.080	0.058
Rat	0.071	0.072	0.058	0.064	0.063	0.051▼	0.069	0.062	0.080	0.058
Sheep	0.005	0.003▼	0.003▼	0.003▼	0.004	0.002▼▼	0.003▼▼	0.003▼▼	0.009▲▲▲	0.003▼▼
Rabbit	0.014	0.014	0.011	0.014	0.013	0.009▼▼	0.011	0.014	0.015	0.009▼▼
Hamster	0.040	0.040	0.031▼	0.037	0.031▼	0.028▼▼	0.033	0.032▼	0.052▲	0.029▼
Cockroach	0.211	0.200	0.194	0.206	0.262▲	0.231	0.209	0.226	0.198	0.270

▲, 20% or more of the average; ▲▲, 30% or more; ▲▲▲, 40% or more; ▼, 20% or less of the average; ▼▼, 30% or less; ▼▼▼, 40% or less.

less accurate than the ImmunoCAP system, but recent studies have shown no significant difference between the two methods [24]. In the early 1990s, the Korean aeroallergen panel was first introduced for MAST [25], and the currently used panel includes about 50 aeroallergens, based on data from patients in three hospitals in Seoul, Suwon, and Jeju around 2001 [21]. Subsequently, many companies have introduced various types of MAST products. Compared with the panel developed in 2001, the MAST aeroallergen panel used in this study has added *A. siro*, olive, white ash, acacia, white pine, reed, plantain, Russian thistle, goldenrod, pigweed, horse, guinea pig, mouse, sheep, rabbit, hamster, and others. According to the manufacturer, the new aeroallergen panel was created by excluding allergens with a low detection rate in the past MAST and adding allergens that are currently known to be newly detected in Korea. It is estimated that the new panel will be more useful in diagnosing allergies in Koreans than the past panel, but no study has compared the two panels directly.

Similar to previous studies, the most commonly detected aeroallergens in this study were DP and DF. The PRs for both allergens were approximately the same, but the PR of DF was approximately 0.01 higher. The actual distribution of DF and DP is 65.3% and 20.6%, respectively, with DF showing an overwhelming predominance [26]. However, the cross-reactivity between DP and DF is high [27]; therefore, the PR of DP was also high. In addition, sensitization to *A. siro* and *T. putrescentiae*, storage mites inhabiting hay and granaries, was detected at a significant frequency [27]. However, it was unclear whether there was cross-reactivity between mites or sensitization to storage mites. Further studies are required to determine the clinical significance of sensitization against these storage mites.

Five types of molds were investigated; only *Alternaria* species (sp.) had a PR exceeding 0.05, and the remaining molds had PRs of less than 0.05. However, another recently published study reported that the PR of molds among Koreans was highest for *A. fumigatus* (11.6%) and lowest for *Alternaria* sp. (4.1%) [23]. This difference may be due to the difficulty in standardizing fungal antigens. Therefore, the results may vary greatly depending on the antigen used and may not reflect actual sensitization.

In Korea, the wind begins to carry grass pollen around in spring, tree pollen in summer, and weed pollen in autumn [28]. However, it is difficult to accurately distinguish each pollen season because they overlap significantly and differ between regions. In particular, pollen allergies have increased due to the warming of the Korean Peninsula. In the case of Jeju, compared to 1970, the annual average temperature had increased by 2°C in 2011, resulting in a 2.5-fold increase in cedar allergies in 15 years [29]. Additionally, an increase in exotic plants is likely to be a factor. Grass has an overall higher PR than trees or weeds. For trees, there was a significant difference between the types. The PR of willow was 0.141, whereas that of alder was only 0.079. For weeds, most PRs were approximately 0.10.

Table 4. Studies on aeroallergen sensitization in Koreans

Published year	No. of subjects	Study area	Allergy test	Common aeroallergen									
				#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
1996 [9]	1,775	Seoul	SPT	DF 77.6%	DP 73.3%	Cat 39.9%	Dog 32.6%	Mugwort 23.4%	Tree 18.8%	Ragweed 18.2%	Grass 14.1%	*Alternaria* 6.7%	
1998 [10]	3,159	Busan	SPT	DF 52.5%	DP 44.5%	Straw dust	Cat	Cockroach	Alder	Birch	Hazel	Beech	Chrysanthemum
2006 [11]	502	Seoul	SPT/MAST	DF 79.4%	DP 68.1%	House dust 43.8%	Cockroach 16.8%	Mugwort 12.3%	Birch/alder 11.7%	Ragweed 11.1%	Dog 11.0%	Bermuda grass 10.2%	Hazel 9.4%
2011 [12]	726	Gangwon	SPT	DP 33.8%	DF 31.0%	Storage mites 14.6%	Rabbit 13.3%	*Candida albicans* 13.0%	Cockroach 10.8%	Mugwort 10.9%	Wood 7.3%	Dog 7.0%	Birch 6.7%
2014 [13]	110	Urban areas	SPT/CAP	DF 40.9%	Cockroach 40.9%	Mugwort 13.6%	Ragweed 1%	Oak 9.1%	Japanese cedar 9.1%	Dog 8.2%			
2014 [14]	634	Ulsan	SPT	DP 38.2%	DF 38.0%	Birch 15.8%	Alder 15.3%	Hazel 14.2%	Oak 13.5%	Beech 10.8%	Mugwort 9.6%	Japanese cedar 5.2%	
2014 [15]	7,182	Seoul	SPT	DF 75.0%	DP 74.7%	Beech 30.6%	Dog 25.9%	Cat 24.3%	Cockroach 22.6%	Mugwort 21.1%	Japanese cedar 20.2%	Chrysanthemum 18.9%	Oak 18.9%
2015 [16]	1,400	Busan	SPT	DF 35.5%	DP 33.3%	Cat 13.9%	Cockroach 11.1%	Dog 10.1%	Birch 10.9%	Alder 10.8%	Beech 9.5%	Oak 9.4%	Mugwort 8.3%
2017 [17]	Adolescents 14,678	5 Regions	SPT	HDM 86.8%	Tree 25.2%	Weed 19.9%	Grass 7.6%	Mold 13.5%					
2017 [18]	28,954	12 Regions	SPT	DF 29.0%	DP 28.2%	Cat 8.1%	Birch 7.7%	Mugwort 6.9%	Alder 6.7%	Hazel 6.7%	Beech 6.7%	Oak 6.6%	*Tyrophagus putrescentia* 6.2%
2019 [19]	14,786	8 Regions	MAST	DF 36.5%	DP 32.3%	Cat 6.8%	Cockroach 6.1%	Russian thistle 5.7%	Sweet vernal grass 5.4%	Dog 5.2%	Reed 5.0%	Rye grass 4.8%	Bermuda grass 4.7%
2021 [20]	7,504	Seoul	SPT	DF 67.5%	DP 66.1%	Cat 20.6%	Mugwort 15.9%	Dog 15.2%	Cockroach 14.4%	Oak 13.1%	Birch 12.4%	Ragweed 7.9%	Candida albicans 7.2%

SPT, skin prick test; DF, *Dermatophagoides farina*; DP, *Dermatophagoides pteronyssinus*; MAST, multiple allergosorbent test; CAP, ImmunoCAP; HDM, house dust mite.

Among animals, cats (0.231) and dogs (0.183) showed very high PRs. However, the PRs were less than 0.1 for horses, rodents, sheep, and rabbits. Further investigation is needed to determine whether there is actual sensitization or cross-reactivity with other common pets like cats and dogs. Cockroaches also showed a high PR of 0.211. According to a study analyzing changes in the aeroallergen sensitization rate of Koreans over the past 30 years, there was little change in the sensitization rate to other indoor antigens, such as mites, molds, and animals [23]. However, the proportion of sensitization against cockroaches decreased from 25.3% in the 1980s to the 1990s to 12.3% in the 2010s [23]. This is thought to have resulted from improved sanitary conditions, but is still considered to be high.

Only one type of positive aeroallergen was found in 44.4% of patients, and 85.1% had three types or fewer. Conversely, about 15% of patients were poly-sensitized (i.e., sensitized to four or more types). On average, one person was sensitized to 2.07 types of aeroallergens; adolescents had the highest average number, at 2.31, while the rest were similar. It has been reported that poly-sensitization causes more severe symptoms, such as nasal congestion and sneezing, and that conjunctivitis and eczema are more common in poly-sensitized patients than in mono-sensitized patients [30]. Although information on the correlation between the number of sensitizing aeroallergens and the severity of symptoms was not available in this study, it is presumed that poly-sensitization is high during adolescence and gradually decreases with age. This is also consistent with the high prevalence of asthma, allergic rhinitis, and atopic dermatitis in adolescents, which decreases with age [1-4].

The distribution of PRs by age differed according to the type of aeroallergen. Most mold PRs in children were very low, changing to very high in adolescents, and decreasing again in adults. In the elderly, the PRs for grass, trees, and weeds were very high. Sensitization to cats and dogs was very high in adolescents and low in the elderly population. For cockroaches, the number of sensitized adolescents was very low, while that for the elderly was very high. An accurate explanation for these differences in the PRs, depending on the aeroallergen, is lacking. It is presumed that the PRs were high for molds and pets (the indoor aeroallergens) and low for pollen because of the decrease in outdoor activities among adolescents [13]. However, it is not well understood why the PR for cockroaches, also an indoor aeroallergen, was high in the elderly. Korea's rapid urbanization, the increase in the number of companion animals, and improved sanitary conditions are suspected to be reasons underlying this difference [23].

The aeroallergen PRs also varied by region. The differences were greater for pollen than for indoor allergens, such as mites, molds, and animals. This is presumed to be because the eastern part of the country is mainly mountainous, and the flora changes depending on the latitude [28]. Jeju is an island away from the mainland and is covered with granite; therefore, the sensitization rate to pollen is quite different from other regions [29]. Although the PR for all pollen was very low, Japanese cedars native to this area showed an overwhelmingly high sensitization ratio, with a PR was 0.222 (5.8 times the national average).

Although this study has the strength of analyzing large-scale data from over 360,000 MASTs collected across Korea, it has the following limitations. First, clinical information regarding the patients was unavailable. However, MASTs would have probably been performed for patients suspected of having a respiratory allergy. Second, although the data were collected from all over the country, the sample was not systematically selected and lacked representativeness. However, since the data were collected from 3,735 hospitals across the country, various patient groups were selected; therefore, we believe that there would be little specific bias. Third, class 1 (0.35–0.69 IU/mL) was used as the positivity criterion, and the results may vary upon changing this criterion. Class 1 was selected as the positivity criterion in this study because the MAST has recently become very accurate, and the measurement level is very similar to that of ImmunoCAP, which has a positivity criterion of 0.35 IU/mL [24]. Fourth, there may have been cases where one person received multiple MASTs, but this possibility could not be confirmed because there was no personally identifiable information in the data. However, it is thought that there would not have been many cases of repeating allergy tests within a short period of 2 and a half years.

From this study, we learned several lessons. First, since Koreans are sensitized to a wide variety of aeroallergens, we do not think it is appropriate to test for allergies with only a small number of aeroallergens. Second, since common aeroallergens were different for each region, the region should be considered when composing an aeroallergen panel. Third, since adolescents are often simultaneously sensitized to various aeroallergens, it is necessary to test them using a sufficient number of items.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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