# Correlation of environmental factors with asthma and rhinitis symptoms in Tulsa, OK

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**Background:** Airborne allergens, pollutants, and climatic changes are known to influence the symptoms of asthma patients.

**Objective:** To correlate airborne fungal spore and pollen concentrations, meteorological data, and airborne pollutants with asthma and rhinitis symptoms to develop predictive models for asthma severity.

**Methods:** Patients from the Tulsa community participated in this study from September 1 to October 31, 2000, by filling out daily symptom diaries and measuring morning and evening peak expiratory flow rates. Air samples were collected using a volumetric spore trap. Meteorological variables and maximum and average pollutants were also included in the analysis. Linear regression analyses were performed for all environmental variables and symptom scores. Forward stepwise multiple regression analyses were performed to determine sets of variables that could be used to predict the conditions of increased symptom severity.

**Results:** Twenty-four patients participated in this study. The predominant spore types included *Cladosporium*, ascospores, and basidiospores. The predominant pollen type was *Ambrosia*. September was unusually hot and dry in Tulsa, but 161 mm of precipitation fell in October, primarily during the last 11 days. Two periods of peak symptoms occurred during the study, the first during the peak week of *Ambrosia* and the second after a 22° C drop in temperature over 6 days. Numerous environmental variables showed significant correlations with symptom scores; however, there was no single predictive model for all symptoms.

**Conclusions:** *Ambrosia* pollen and other environmental variables, including ozone levels, were significantly correlated with asthma and rhinitis symptoms.

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## INTRODUCTION

Airborne allergens, as well as climatic changes and airborne pollutants, may influence the symptoms of asthma patients.[1–6] Because the abundance and specific types of spores and pollen differ according to meteorological conditions, there may be similar correlations between asthma symptoms and weather and symptoms and spores. As a result, it is not always clear which environmental factors are responsible for the daily variation in asthma symptom severity. Although there is a general understanding of the meteorological conditions required for the predominant airborne fungal spores and pollen grains to be at peak levels in the atmosphere, these relationships are complex and have not been definitively established in the aerobiology literature.

Asthma is closely linked to hay fever or rhinitis. A recent study reported that 95% of patients with allergic asthma have nasal allergies as well.[7] There is conflicting evidence, however, about the role that pollen concentrations play in the severity of asthma symptoms, with some evidence of a correlation and some studies finding no association between asthma and pollen.[8–10] Exposure to the starch granules from pollen grains have been shown to elicit severe bronchial constriction.[11] One study of patients with seasonal asthma and rhinitis concluded that grass pollen immunotherapy reduced seasonal asthma symptoms and bronchial hyperresponsiveness.[12] Interactions between pollen and ozone have been shown to lessen the amount of allergen necessary to initiate an asthmatic response.[13]

There is evidence that every major fungal group contains allergens.[14–16] Both indoor and outdoor exposure are important and may cause asthma, hay fever, and hypersensitivity pneumonitis in sensitive patients. There is a great deal of overlapping sensitivity to different types of fungal spores. It has been suggested that prolonged exposure to one allergenic spore type creates a base level of susceptibility, which can easily be increased with the addition of other spore and pollen types, such as grass pollen, *Penicillium*, *Alternaria*, and *Aspergillus*, resulting in an allergic response and an asthma attack.[17]

If the relationship among asthma symptoms, meteorological conditions, and bioaerosol concentrations could be conclusively established, this could provide a huge benefit to patients with known outdoor allergies. Knowledge of this relationship would allow allergy and asthma patients to take preventive measures before being exposed to high concentrations of particular allergens. This project attempts to correlate various asthma symptoms and peak expiratory flow rate (PEFR) readings from local asthma patients with atmospheric fungal spore and pollen concentrations and meteorological and air pollution data. The goal of the project was to develop an exploratory model that links asthma severity and 1 or more predictors from the bioaerosol, pollutant, and meteorological data.

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## METHODS

The study was conducted from September 1, 2000, to October 31, 2000, 2 months when both pollen and spore levels are typically elevated in Tulsa, OK.[18,19] The analysis included daily averages of weather, pollutants, spores, pollen, and symptom variables. PEFR readings were analyzed for both morning and night.

Volunteers were recruited for this project through fliers sent to area physicians, a newspaper article, and e-mail solicitation on The University of Tulsa mail server. Proper use of the peak flow meters was demonstrated, and all questions were addressed at a participant meeting. A patient information sheet was completed by every participant before data collection began. This form aided in the analysis of the results and in developing an overall characterization of the patient base by providing medical history and lifestyle information.

Each day during the study, the participants recorded a morning PEFR reading, an evening PEFR reading, medications taken, and other symptoms listed in a symptom diary. Table 1 shows a sample of the symptom diary; in the actual diary, patients were instructed to check yes for each symptom experienced during the day. Diaries were for 1 week, and there was a separate dated column for each day. Symptom diaries were modeled after ones used by O'Rourke et al[20–22] from The University of Arizona College of Medicine. The diaries were validated by these researchers and used in asthma studies of a white, middle-class population in Tucson, AZ. Symptom diaries and all forms were approved by The University of Tulsa Human Subjects Review Board, and an informed consent form was signed by each participant.

Pollen and fungal spore levels in the Tulsa atmosphere were monitored using a Burkard volumetric spore trap (Burkard Manufacturing Co, Ltd, Rickmansworth, UK) located on the roof of Oliphant Hall at The University of Tulsa as previously described.[23] The slides were analyzed at 400× for pollen using the 12-traverse method. Fungal spores were counted at 1,000× under oil immersion using the longitudinal method. The spore and pollen counts were converted into atmospheric concentrations and expressed as spores or pollen grains per cubic meter of air. The bioaerosol concentrations were log transformed to normalize the data for statistical analyses.

Table 1. Sample of the Symptom Diary Used in This Study

| | |
|---|---|
| AM Peak expiratory flow rate (PEFR) | ________ |
| PM Peak expiratory flow rate (PEFR) | ________ |
| Red, itchy, watery, or burning eyes | ☐ Yes |
| Stuffy or running nose | ☐ Yes |
| Sore throat | ☐ Yes |
| Cough | ☐ Yes |
| Chest cold | ☐ Yes |
| Sneezing | ☐ Yes |
| Wheezing | ☐ Yes |
| Chest tightness | ☐ Yes |
| Shortness of breath | ☐ Yes |
| Dryness of the mouth | ☐ Yes |
| Fever or a feverish feeling | ☐ Yes |
| Dizziness | ☐ Yes |
| Headache | ☐ Yes |
| Unusual fatigue, tiredness, achy feeling | ☐ Yes |
| Other symptoms | ☐ Yes |
| Missed work or school | ☐ Yes |
| Consulted a physician | ☐ Yes |
| Emergency room visit | ☐ Yes |
| *Medications taken | ________ |

* Please write the medication name and the number of puffs, pills, or teaspoons taken.

Meteorological data were obtained from the National Oceanic and Atmospheric Administration weather station in Tulsa, located approximately 8.0 km northeast of the sampling site. Pollution data, including the daily averages and daily maximums for ozone, carbon monoxide, particulate matter less than or equal to 2.5 $\mu$m, and sulfur dioxide, were obtained from the Oklahoma Department of Environmental Quality sampling site, located approximately 1.0 km from The University of Tulsa.

A percentage of positive responses for each symptom for each day was calculated using the number of positive responses and the total number of patients responding that day. A composite asthma score for each day was calculated by adding the ratio of positive responses for wheezing, chest tightness, shortness of breath, and coughing. This number was converted to a decimal with a range of 0.0 to 4.0. A 4.0 would have meant that every patient had exhibited every asthma symptom on a given day. A composite rhinitis symptom score was calculated in the same manner using the symptoms itchy or watery eyes, runny nose, sore throat, cough, and sneezing. This score was out of a possible 5.0.

Both simple linear regression and forward stepwise multiple regression analyses (using Statistica 5.0 software, StatSoft Inc, Tulsa, OK) were performed for each individual symptom and for the morning and evening peak flow values. The patient categories for the multiple regression analyses included all patients, patients not exposed regularly to tobacco smoke, men, and women. The predictor variables included all of the meteorological variables and each spore and pollen type that had an average daily value of more than 1 particle/m$^3$ during the 2-month period and the mean and maximum pollutant levels. Analyses were also conducted for each symptom to determine whether lag effects were present for the period up to 5 days before reported symptoms.

## RESULTS

### *Summary of Patient Group*

Although 38 patients completed initial paperwork, only 24 patients completed at least a portion of the diaries and thus were included in the analysis (Table 2). All patients had a physician diagnosis of asthma; however, skin testing information was not available to the authors of the current study. On the information forms, the average participant experi-

Table 2. Patient Group Characteristics

| Characteristics | Male | Female | Total |
|---|---|---|---|
| No. of patients | 5 | 19 | 24 |
| Average age, y | 31 | 38 | 36 |
| Age range, y | 9–45 | 9–64 | 9–64 |
| Average years with asthma | 19 | 17 | 17 |
| Average days per week with symptoms | 5 | 4 | 4 |
| Average nights per week with symptoms | 4 | 4 | 4 |
| Percentage of the time you take asthma medication | 76–100 | 51–75 | 51–75 |
| Someone around you smokes, % of patients | 20 | 26 | 25 |
| Admitted to the hospital due to asthma, % of patients | 60 | 42 | 46 |
| Received ventilatory support because of asthma, % of patients | 40 | 21 | 25 |
| Average No. of family members with asthma or allergies | 1 | 2 | 2 |
| Physically active, % of patients | 100 | 74 | 79 |

enced asthma-related symptoms approximately 4 days and 4 nights each week, although most indicated that this number was extremely variable from week to week. The number of previous hospital visits was highly variable from patient to patient.

The composite asthma symptom scores show definite periods of increased asthma symptoms (Fig 1A). The days with the highest symptoms were September 18 and October 7, both days having a score of 1.33. The composite rhinitis scores were similar to the asthma symptom scores, although the value of the scores cannot be directly compared (Fig 1B). The peaks were on September 19 and 20, with scores of 1.81 and 1.70, respectively, and October 7 and 8, with scores of 1.73 and 1.60, respectively. Smaller peaks in both scores were seen on October 16 and October 27 to 29.

The mean morning PEFR was 375 L/min, the mean evening PEFR was 368 L/min, and the total average PEFR was 371 L/min (Fig 2). The evening PEFR averages were less than the morning average on 45 days and greater than the morning average PEFR on 16 days during the study. Days when both PEFR values were below 360 L/min included September 10 and October 3. During the periods of peak symptom scores, PEFR readings were lower than the mean. The PEFR values on September 18 and 19 averaged approximately 365 L/min for the evening PEFR and approximately 370 L/min for the morning PEFR. PEFR values for the second period of peak symptoms (October 7–9) showed val-

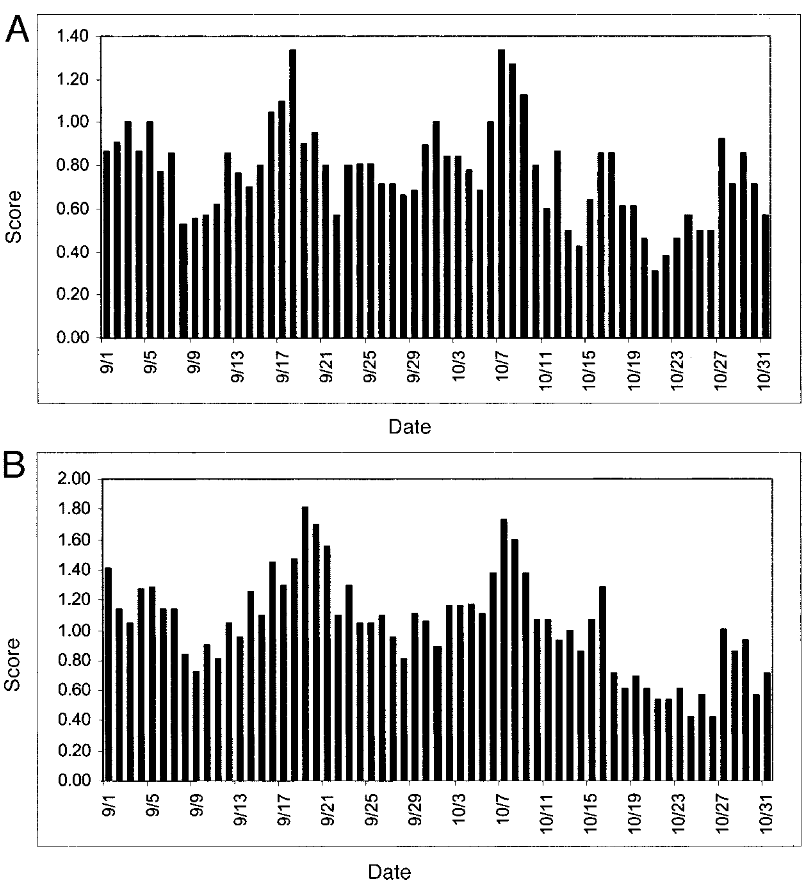


Figure 1. Composite asthma and rhinitis symptom scores. The scores were calculated by adding percentages of positive responses for all symptoms in the category. Top, Composite asthma symptom score includes cough, chest tightness, wheezing, and shortness of breath. Maximum possible score is 4.0. Bottom, Composite rhinitis symptom score includes itchy/watery eyes, stuffy/runny nose, sore throat, cough, and sneezing. Maximum possible score is 5.0. All dates are for 2000.

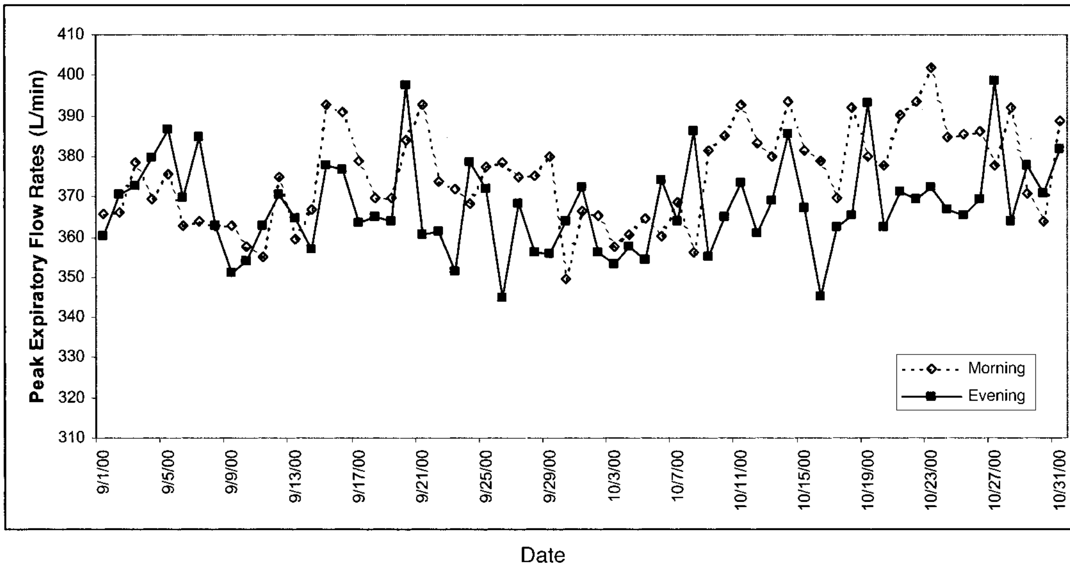


Figure 2. Average peak expiratory flow rates.

ues between 360 and 370 L/min on October 7 and a value of 356 L/min on the morning of October 8, which was one of the lowest average morning PEFRs.

*Weather Summary*

The conditions during the study period of September 1 to October 31, 2000, were much warmer than normal (Table 3). The day with the highest average temperature was the first day of the study at 33.33° C, and the lowest was on October 8 at 5.56° C (Fig 3). There was a large increasing trend from September 24 until October 3, and then the average temperature dropped each day until October 8, at which point the temperature began to rise again until October 13.

The total precipitation was 189 mm (Table 3), with 122 mm (65% of the total) falling during the last 11 days of October (Fig 3). September had 79.74 mm less precipitation than normal, but October had 70.63 mm more than normal. The month previous to the study had been especially hot and dry, with the maximum temperatures averaging 3.16° C above normal and with 78.99 mm less precipitation than normal.

*Concentrations of Bioaerosols and Pollutants*

The average daily concentrations of the spore and pollen types identified in this study are listed in Table 4. *Cladosporium* represented 82.2% of the total atmospheric fungal spores during the study period. The next most abundant were ascospores, basidiospores, smut spores, and *Alternaria*.

The airborne *Cladosporium* spore levels initially remained between approximately 2,500 and 12,500 spores/m$^3$ until October 16 (Fig 4, top). *Cladosporium* concentrations increased during the next 4 days, reaching 24,030 spores/m$^3$ on October 20. The concentrations decreased until October 24, then peaked at 27,942 spores/m$^3$, the highest concentration for the study period. This rise in levels corresponded to the heavy rainfall seen in late October.

The ascospore concentrations showed a much different pattern during the study period (Fig 4, bottom). The highest concentrations were on September 5 and 12, with concentrations of 3,005 and 2,258 spores/m$^3$, respectively. Both of these peaks followed relatively small amounts of rain; however, the days leading up to that precipitation were com-

Table 3. Meteorological Summary of Study Period

| Variable | September 2000 | | October 2000 | |
|---|---|---|---|---|
| | Average (range) | 30-Year average | Average (range) | 30-Year average |
| High temperature, °C | 31.94 (16.11–42.22) | 29.22 | 25.07 (12.22–33.33) | 23.72 |
| Low temperature, °C | 16.59 (5.56–25.00) | 17.22 | 13.54 (−2.22–20.00) | 10.50 |
| Mean temperature, °C | 24.39 (13.33–33.33) | 22.94 | 19.1 (5.56–27.22) | 17.11 |
| Average dew point, °C | 13.28 (5.00–20.00) | 15.72 | 11.45 (−5.56–18.89) | 9.56 |
| Relative humidity, % | 54.01 (29.50–94.38) | 70.00 | 66.25 (40.88–92.37) | 66.00 |
| Total precipitation, mm | 27.96 (0.00–12.70) | 118.87 | 161.05 (0.00–41.91) | 92.96 |
| Average pressure, mm Hg | 742.97 (736.35–749.30) | 744.47 | 746.88 (736.35–760.48) | 745.24 |
| Average wind speed, m/s | 3.95 (1.03–7.51) | 4.02 | 4.24 (1.56–7.19) | 4.29 |

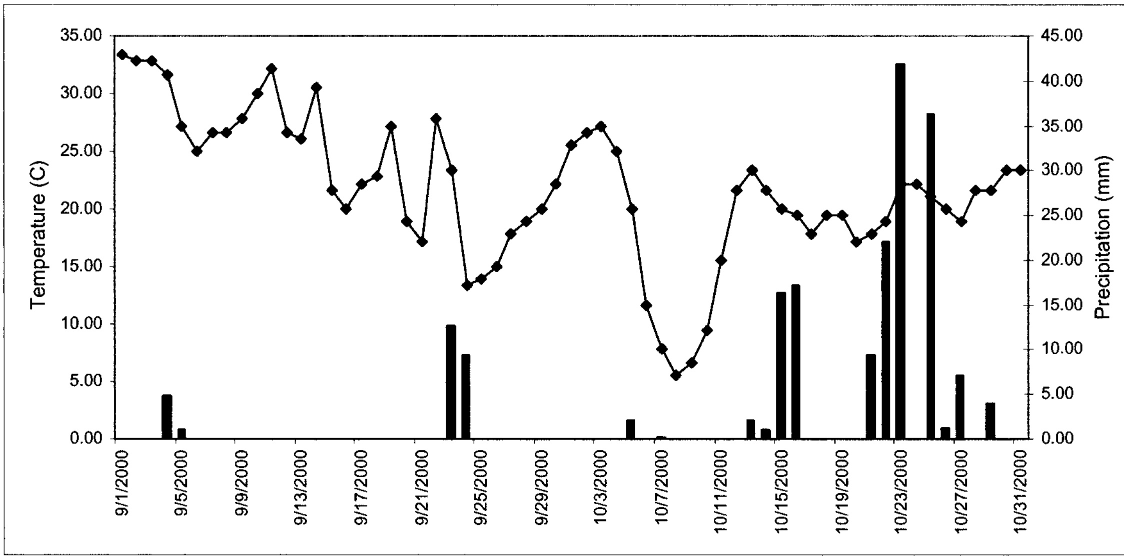


Figure 3. Precipitation and average temperature during the study period.

Table 4. Average Daily Concentrations of Bioaerosols and Pollutants during the Study Period (n = 61)

| | Average (range) |
|---|---|
| Fungal spores, particles/m$^3$ | |
| *Cladosporium* | 8,151 (1,140–27,942) |
| *Alternaria* | 211 (0–663) |
| *Drechslera* | 37 (0–106) |
| *Epicoccum* | 16 (0–111) |
| *Pithomyces* | 11 (0–74) |
| *Curvularia* | 10 (0–37) |
| Ascospores | 675 (21–3,005) |
| Basidiospores | 542 (0–3,699) |
| Smut spores | 220 (5–790) |
| Other spores | 143 (0–339) |
| Pollen, particles/m$^3$ | |
| *Ambrosia* | 107 (1–498) |
| *Ulmus* | 9 (0–167) |
| Chenopodiaceae/Amaranthoceae | 5 (0–24) |
| Poaceae | 3 (0–13) |
| All other pollen | 1 (0–16) |
| Pollutants, ppm | |
| Particulate matter $\leq$ 2.5 $\mu$m | 13.07 (0.50–29.90) |
| Carbon monoxide | 0.57 (0.30–1.60) |
| Ozone | 0.03 (0.01–0.07) |
| Sulfur dioxide | 0.01 (0.00–0.02) |

pletely dry. The concentrations also began to rise beginning on October 21, corresponding to the beginning of 7 consecutive days of rainfall. The added rainfall appeared to have helped the concentrations rise to 1,993 spores/m$^3$ on October 27 and 2,152 spores/m$^3$ on October 31.

The basidiospore concentrations followed a very steady pattern for the first 50 days of the study, with concentrations consistently below 500 spores/m$^3$ (Fig 4, bottom). During the final 11 days, the basidiospore concentrations continued on a generally upward trend, with the highest concentration, 3,699 spores/m$^3$, on the last day of the study. This was presumably in response to the significant increase in rainfall during these days. The increase in the various fungal spore levels near the end of the study coincides with a small increase in symptom scores seen during this period.

The most common types of pollen identified were *Ambrosia*, *Ulmus*, Chenopodiaceae/Amaranthaceae, and Poaceae (Table 4). *Ambrosia* represented 85.8% of the total atmospheric pollen during the study period. The *Ambrosia* concentrations were the highest in September, especially from September 11 to 23 (Fig 5). Peak days were September 15, 20, and 23, with concentrations of 353, 498, and 369 pollen grains/m$^3$, respectively. After September 23, the concentrations dropped below 100 pollen grains/m$^3$, with a slight resurgence from October 2 to 5. After October 5, the *Ambrosia* concentration remained extremely low. The next most abundant pollen was *Ulmus*, which was 7.1% of the total pollen. Ten other pollen types (*Alnus*, *Artemesia*, *Betula*, *Carya*, *Celtis*, *Juniperus*, *Maclura*, *Morus*, *Plantago*, and *Urtica*), with an individual mean concentration below 1.0 pollen grains/m$^3$, were excluded from further analysis. These taxa compose the group "other pollen." Table 4 also shows the mean concentrations of airborne pollutants examined in the study.

*Regression Analysis*

Simple linear regression analyses showed that several environmental factors were significantly related to patient symptoms. *Ambrosia* concentrations were significantly correlated with composite asthma scores ($r$ = 0.263, $P$ < .05) and rhinitis scores ($r$ = 0.513, $P$ < .001) and several individual symptoms (Table 5). Pollen from the Chenopodiaceae/Ama-

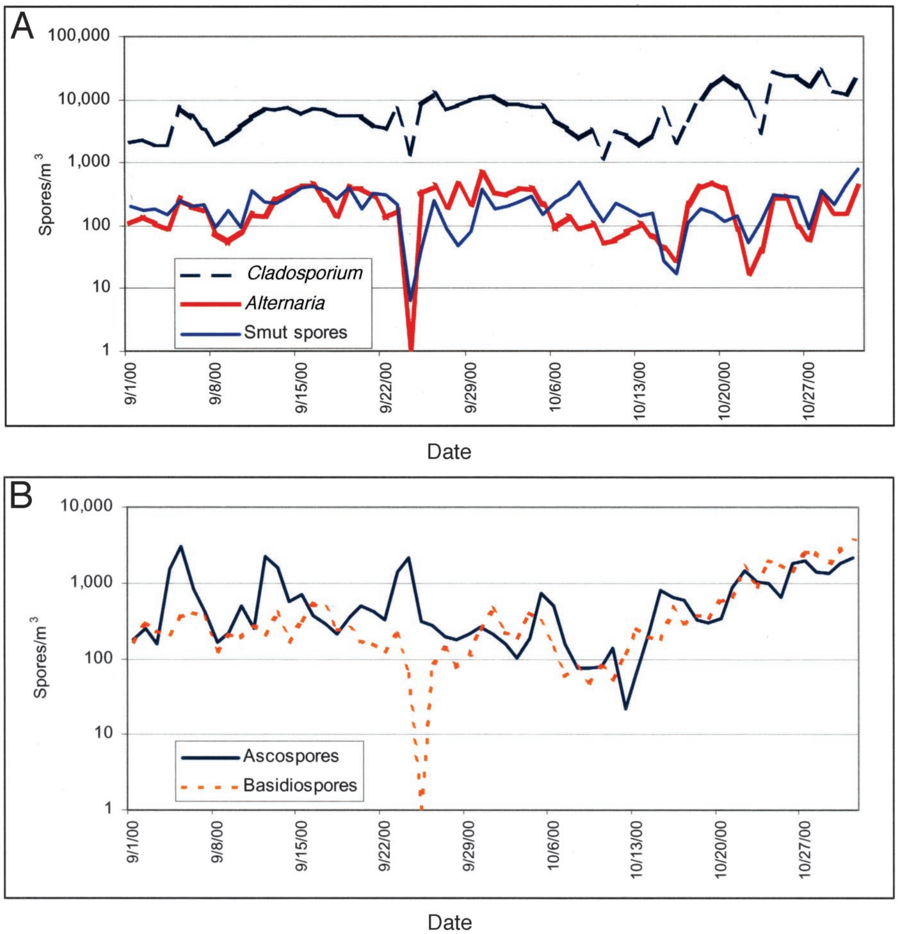


Figure 4. Average daily concentrations of major airborne fungal spores. Top, *Cladosporium*, *Alternaria*, and smut spores. Bottom, Ascospores and basidiospores.

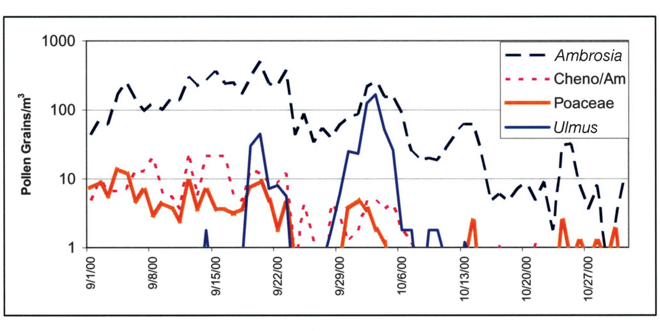


Figure 5. Average daily concentrations of major airborne pollen. Cheno/Am, Chenopodiaceae/Amaranthaceae.

ranthaceae families also showed significant correlations with composite asthma scores ($r = 0.256$, $P < .05$), and pollen from *Ulmus* ($r = 0.367$, $P < .01$), Chenopodiaceae/Amaranthaceae ($r = 0.458$, $P < 0.001$), and Poaceae ($r = 0.326$, $P <$ .05) had significant correlations with composite rhinitis scores. Several individual symptoms also showed significant correlations with these pollen types (data not shown). Pollen concentrations significantly influenced morning PEFR readings for the following day. Morning PEFRs were negatively correlated with pollen concentrations of *Ambrosia* ($r = -0.364$, $P < .01$), *Ulmus* ($r = -0.261$, $P < .05$), Chenopodiaceae/Amaranthaceae ($r = -0.362$, $P < .01$), and Poaceae ($r = -0.285$, $P < .05$); however, evening PEFR readings showed no significant relationship with pollen concentrations for the previous day or the current day. Patient symptom scores showed little relationship to fungal spore concentrations. Morning PEFR readings were negatively related to concentrations of *Curvularia* ($r = -0.27$, $P < .05$) and *Drechslera*-type conidia ($r = -0.34$, $P < .01$).

Significant relationships between symptoms and meteorological conditions also existed (Table 6). Composite asthma symptom scores showed a significant increase as morning low temperatures decreased ($r = -0.317$, $P < .05$). Dew point and relative humidity were negatively related to both composite asthma and rhinitis scores. Precipitation was also negatively correlated with these composite scores; however, the relationship with the rhinitis symptoms was not significant. Similar results were seen with individual symptom scores, with dew point and relative humidity as the most

Table 5. Correlations of Symptom Scores with Airborne *Ambrosia* Concentrations

| Symptoms | Pearson correlation coefficient |
|---|---|
| Composite asthma score | 0.263* |
| Composite rhinitis score | 0.513† |
| AM PEFR | −0.364‡ |
| PM PEFR | −0.121 |
| Red, itchy, watery eyes | 0.593† |
| Stuffy or runny nose | 0.568† |
| Sore throat | 0.211 |
| Cough | 0.147 |
| Chest cold | −0.271* |
| Sneezing | 0.272* |
| Wheezing | 0.363‡ |
| Chest tightness | 0.042 |
| Shortness of breath | 0.255* |
| Dry mouth | 0.264* |
| Fever | 0.061 |
| Dizziness | 0.347‡ |
| Headache | 0.229 |
| Fatigue | 0.463† |

Abbreviation: PEFR, peak expiratory flow rate.
* $P \leq .05$.
† $P \leq .01$.
‡ $P \leq .001$.

important variables (data not shown). For the atmospheric pollutants, average and maximum ozone concentrations seemed to be the most significant factors that influenced symptom scores. Morning PEFR values were significantly affected by average ($r = -0.274$, $P < .05$) and maximum ($r = -0.289$, $P < .05$) ozone levels on the previous day. Individual symptoms, such as wheezing, headache, and fatigue, were also significantly related to the average and maximum daily ozone levels (data not shown).

Because of the complex relationships between symptom scores and environmental factors, multiple regression analysis was used in an attempt to develop predictive models to integrate these relationships. Multiple regression analyses were performed for all patients (n = 24), men (n = 4), women (n = 18), and those patients not exposed to tobacco smoke on a regular basis (n = 19). Each analysis correlated one symptom for a specific patient category with a combination of the environmental variables to produce a model explaining a percentage of the variability ($R^2$) for the symptom. The multiple regression analysis produced different predictive models for each symptom using combinations of all environmental factors: 8 meteorological parameters, 10 spore types, 4 pollen types, and 8 pollutant categories. Eight separate regression models were produced for each symptom for each patient category, for a total of 32 possible models per symptom, to ensure that the environmental variables did not autocorrelate. For example, relative humidity and dew point were not used together, average temperature was not used with high and low temperature, and average pollutants were not used in the same regression with maximum pollutants. Some of the best predictive models are displayed in Tables 7 and 8. $\beta$ values are only displayed for the variables that were significant at $P < .05$. Shaded boxes indicate variables not used for a particular model, whereas blank boxes indicate variables that were excluded by the model or were not significant ($P > .05$) in the regression. Each model includes other nonsignificant variables not listed in the table.

The best predictive models for each patient category for the composite asthma symptom scores each had an $R^2$ of at least 0.573, with women having the best $R^2$ at 0.662 (Table 7). All included either dew point or relative humidity as the best predictor, and each also included Poaceae, although concentrations were low throughout the study.

The best predictive models for the rhinitis composite scores for each patient category all had $R^2$ values between 0.498 (men) and 0.801 (all patients) (Table 7). Dew point or relative humidity was the most important factor in 2 of the models, and average temperature or low temperature was the most important in the other 2.

Table 8 includes the best predictive models for morning and evening PEFR and individual symptoms for the patient group not exposed to tobacco smoke. The morning and evening PEFRs were lagged 1 day, so the symptoms were correlated with environmental variable from the previous day. These were the only factors where lagging the environmental variables increased the value of the $R^2$. Several symptoms were not in the multiple regression analyses (Table 7), because symptoms occurred too infrequently in the patient

Table 6. Correlation of Symptom Scores with Meteorological Variables

| Meteorological variable | Pearson correlation coefficients | | |
|---|---|---|---|
| | Composite asthma score | Composite rhinitis score | Morning PEFR |
| Average daily temperature | −0.189 | −0.113 | −0.300* |
| Low temperature | −0.317* | −0.247 | −0.242 |
| Average dew point | −0.508† | −0.432† | −0.184 |
| Average relative humidity | −0.537† | −0.556† | 0.194 |
| Precipitation | −0.324* | −0.244 | 0.263 |

Abbreviation: PEFR, peak expiratory flow rate.
* $P \leq .05$.
† $P \leq .001$.

Table 7. Multiple Regression Predictive Models*

| | $R^2$ | Average temperature | Dew point | Relative humidity | Wind speed | *Cladosporium* | *Alternaria* | *Epicoccum* | Basidospores | Poaceae | Average CO | Average $PM_{2.5}$ | Average $SO_2$ | Maximum $PM_{2.5}$ | Maximum $SO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Significant $\beta$ values for asthma | | | | | | | | | | | | | | |
| All patients (n = 24) | 0.573† | −0.46 | | −0.68 | | | | | 0.24 | 0.40 | | −0.27 | | | |
| Not exposed to smoke (n = 19) | 0.592† | | | −0.50 | | | −0.32 | 0.35 | | 0.33 | | | | −0.29 | −0.26 |
| Men (n = 4) | 0.559† | 1.00 | −1.00 | | −0.32 | 0.55 | −0.81 | 0.28 | | 0.43 | 0.35 | −0.55 | | | |
| Women (n = 18) | 0.662† | −0.45 | | −0.61 | | | | | | 0.39 | | | −0.32 | | |

| | $R^2$ | Average temperature | Low temperature | Dew point | Relative humidity | Pressure | Wind speed | *Cladosporium* | *Curvularia* | Smut spores | *Ulmus* | Poaceae | Average CO | Average $PM_{2.5}$ | Average $SO_2$ | Maximum $PM_{2.5}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Significant $\beta$ values for rhinitis | | | | | | | | | | | | | | | |
| All patients (n = 24) | 0.801† | | | −0.62 | | −0.34 | | −0.22 | | 0.19 | | 0.41 | | | −0.37 | |
| Not exposed to smoke (n = 19) | 0.692† | −0.78 | | | −0.59 | −0.53 | | | | | | | −0.23 | −0.28 | | |
| Men (n = 4) | 0.498† | | −0.56 | | | | | | 0.36 | | | | | | | −0.35 |
| Women (n = 18) | 0.790† | | | | −0.67 | | 0.33 | | −0.18 | | 0.18 | | | | −0.63 | |

Abbreviations: CO, carbon monoxide; $PM_{25}$, particulate matter less than or equal to 2.5 $\mu$m; $SO_2$, sulfur dioxide.
* Shaded areas indicate variables not included in the regression.
† $P < .001$.

population during the study to produce any well defined relationships with predictive variables.

## DISCUSSION

This study examined the relationships between environmental factors and asthma and rhinitis symptoms among a group of asthmatic patients recruited from the general community. Findings show significant correlations between symptom scores and various pollen types, meteorological factors, and ozone levels. In particular, *Ambrosia* pollen levels were significantly related to a number of individual symptoms and composite asthma and rhinitis scores. Several previous studies have linked asthma exacerbation with pollen exposure,[6,9,11,21,24,25] but this is the first study, to our knowledge, to show a connection with *Ambrosia* pollen.

The other pollen types analyzed were also significant variables that influenced the symptom scores; however, some of this may be due to colinearity. There were significant correlations between *Ambrosia* pollen concentrations and the concentrations of *Ulmus* ($r = 0.45$, $P < .001$), Poaceae ($r = 0.67$, $P < .001$), and Chenopodiaceae/Amaranthaceae ($r = 0.82$, $P < .001$) pollen. The likely explanation for these correlations is that the pollen release mechanisms in these taxa were responding in a similar manner to meteorological conditions. In fact, concentrations of *Ambrosia*, Poaceae, and Chenopodiaceae/Amaranthaceae all showed significant positive correlations to temperature and negative correlations with relative humidity, precipitation, and atmospheric pressure (data not shown).

There were 2 main periods during the study when both asthma and rhinitis symptom scores were the greatest. The first period (September 18–19) was during the peak *Ambrosia* season. Although the peak symptoms and below average PEFR did not correlate exactly with the peak pollen day (September 20), regression analyses showed positive correlations between *Ambrosia* pollen concentrations and symptom scores. Also, elevated concentrations from the previous 15 days could have had an additive effect, resulting in heightened symptoms on the September 18 and 19. More than 40% of the patients reported increasing their medications during that week, which could account for the discrepancy between the symptom peak and the *Ambrosia* peak. If the patients started taking higher doses of medication at the beginning of the *Ambrosia* increase, by the time that *Ambrosia* was at its highest concentration on September 20, the patients may have partially controlled for that allergen. There is also the possibility that the *Ambrosia* concentrations may have been slightly different at various locations around the city, since concentrations were only recorded from the sampler at The University of Tulsa.

The next period of high symptoms was from October 7 to 9. The temperature was almost to the bottom of a massive decline. The average temperature fell from 27° C on October 3 to 5° C on October 8, and linear regression analysis showed there was a significant increase in composite asthma symptom scores as morning low temperatures decreased. Small

Table 8. Multiple Regression Predictive Models for Other Symptoms*

| | | Significant $\beta$ values for other symptoms§ | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $R^2$ | Average temperature | High temperature | Low temperature | Dew point | Relative humidity | Precipitation | Pressure | Wind speed | *Cladosporium* | *Epicoccum* |
| Morning PEFR¶ | 0.552† | | | 0.91 | −1.78 | | 0.31 | −0.77 | −0.49 | | −0.45 |
| Evening PEFR¶ | 0.551‡ | | 0.86 | | | | −0.35 | | 0.16 | −0.45 | |
| Itchy, watery eyes | 0.662† | | −0.96 | | | −0.75 | | −0.46 | | | |
| Stuffy, runny nose | 0.683† | −0.53 | | | | −0.33 | | −0.58 | | | |
| Cough | 0.541‡ | | −1.04 | | | −0.83 | | −0.70 | −0.39 | | |
| Sneeze | 0.468† | | | | −0.61 | | | | | | |
| Wheeze | 0.356‡ | | | | | −0.46 | | | | | 0.31 |
| Chest tightness | 0.565‡ | | 0.84 | | −0.85 | | | | 0.39 | | |
| Shortness of breath | 0.665‡ | | | | | | −0.32 | | | | 0.38 |

Abbreviations: $O_3$, ozone; PEFR, peak expiratory flow rate; $PM_{2.5}$, particulate matter less than or equal to 2.5 $\mu$m; $SO_2$, sulfur dioxide.
* Shaded areas indicate variables not included in the regression.
† $P < .001$.
‡ $P < .01$.
§ For patients not exposed to tobacco smoke.
¶ Models were lagged 1 day.

peaks occurred on October 16 and October 27 to 29. During this period, fungal spore levels increased, especially ascospores and basidiospores. It is possible that these may be related to the elevated symptoms. Basidiospores were one of the significant factors for asthma symptoms for the whole group in the multiple regression analysis but not the simple linear regression. Both Epton et al[8] and Dales et al[10] have shown increased asthma severity with rises in basidiospore concentrations, and Dales et al[10] also documented associations with increased airborne ascospore concentrations.

The multiple regressions for symptoms presented herein included a variety of variables as the top predictors for each symptom but no consistent set of triggers. There are many possible explanations. Some variables may be autocorrelated, since it is well known that ascomycete fruiting bodies need precipitation and/or high humidity to trigger ascospore release, and *Cladosporium* and other dry air spores tend to be released on warm, dry days with strong winds.[14,26] Some variables may also have been colinear as described earlier. Different variables may also have been significant if the regressions analyzed each month separately. For example, *Ambrosia* was a significant predictor for rhinitis in models for September (data not shown) but not in the models for both months, even though simple linear regression analysis showed that *Ambrosia* pollen levels were significantly related to symptom scores for the whole period.

The inclusion of Poaceae pollen as a significant variable in the predictive models for asthma was surprising, because average daily grass pollen concentrations were low to moderate throughout the period based on National Allergy Bureau pollen levels. It is possible that colinearity with ragweed pollen may explain this; however, studies have suggested that grass pollen levels as low as 10 to 20 grains/$m^3$ are sufficient to trigger symptoms in sensitive individuals.[27,28] Although the 2-month mean concentration was below this level, many daily concentrations were in the moderate range, and hourly concentrations were in the high range (>20 grains/$m^3$ based on National Allergy Bureau) several times. Clearly, more work is needed with patients known to be grass sensitive.

Different individuals are allergic to different allergens and triggers, so it is entirely possible that one subset of patients was driving the symptom scores on days with high ascospore levels, for example, whereas others showed greater signs of respiratory trouble when the *Ambrosia* or Poaceae concentrations were elevated. This would have resulted in weaker regressions with any particular allergen or environmental factor. If skin testing data had been available, patients could have been grouped by pollen sensitivity. Also, our volunteer population was not necessarily representative of all asthmatic patients in the Tulsa area.

The inconsistencies in the predictive models for the different symptoms also could have been due in part to factors that were not even considered. Personal ozone levels were found to be significant to asthma severity in a study by Delfino et al.[2] Several studies have shown that outdoor concentrations of ozone do not explain personal ozone variability[29]; however, personal exposure data were not available in this study. Individual exposure to tobacco smoke is also a known asthma irritant.[13] Neither the daily variation in tobacco smoke exposure nor exposure to indoor allergens was considered, which could have influenced the severity of asthma symptoms for some patients.

Time-series data have been shown to produce positive associations between fungal spore levels and asthma symptom scores.[2] It is likely that some spore and pollen types, and possibly weather variables, influence asthmatic symptoms sooner than others. The lag time may be as much as 24 or 48 hours previous to the day in question, or responses may be immediate. Most likely, the response time encompasses both reactions to present allergens in the atmosphere and from

Table 8. *Continued*

| Significant β values for other symptoms[§] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Drechslera* | Smut spores | Ascospores | *Ulmus* | *Ambrosia* | *Poaceae* | Average $PM_{2.5}$ | Average $SO_2$ | Maximum $O_3$ | Maximum $PM_{2.5}$ | Maximum $SO_2$ |
| −0.54 | | | | | 0.36 | | | −0.69 | | |
| | 0.38 | 0.44 | | | | | −0.87 | | | |
| | | | | 0.28 | | −0.23 | −0.48 | | | |
| | | | | | | | | | | |
| | 0.35 | | | | | | | | −0.24 | |
| | | | 0.28 | | | | | | | |
| | | | | | | | | | −0.30 | −0.31 |
| | | | | | | | | | | |
| | | | 0.25 | | | | | | −0.28 | |

exposures previous to the symptom occurrence. This study examined delays for up to 5 days previously for all variables and 1-day delays for single variables. This did not improve the outcome of the regressions for any symptom except PEFR; however, better $R^2$ values may have resulted from lagging specific combinations of variables and not others. Clearly, the exploratory models developed in this study need to be validated by further research with a greater number of patients with known skin testing results.

## CONCLUSION

This study showed 2 periods of increased asthma and rhinitis symptoms during September and October 2000, one during the week of peak *Ambrosia* pollen and the other after a 22° C temperature decrease during 6 days. Composite asthma scores, rhinitis scores, and individual symptoms were significantly correlated to *Ambrosia* pollen levels and other pollen types, meteorological conditions, and ozone levels. Multiple regression analyses produced complex models with different predictor variables for each symptom.

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## REFERENCES


1. Shapiro GG. The ABCs of asthma. *Discover*. 1998;19:S21–S24.
2. Delfino RJ, Coate BD, Zeiger RS, et al. Daily asthma severity in relation to personal ozone exposures and outdoor fungal spores. *Am J Respir Crit Care Med*. 1996;154:633–641.
3. Delfino RJ, Zeiger RS, Seltzer JM, et al. The effect of outdoor fungal spore concentrations on daily asthma severity. *Environ Health Perspect*. 1997;105:622–635.
4. Richardson MJ. The occurrence of airborne *Didymella* spores in Edinburgh. *Mycol Res*. 1996;100:213–216.
5. Celenzia A, Fothergill J, Kupek E, Shaw RJ. Thunderstorm associated asthma: a detailed analysis of environmental factors. *BMJ*. 1996;312:604–607.
6. Venables KM, Allitt U, Collier CG, et al. Thunderstorm-related asthma: the epidemic of 24/25 June 1994. *Clin Exp Allergy*. 1997;27:725–736.
7. Corren J, Busse WW. Connecting hay fever to bronchial asthma. *Discover*. 1999;20:15–20.
8. Epton MJ, Martin IR, Graham P, et al. Climate and aeroallergen levels in asthma: a 12 month prospective study. *Thorax*. 1997; 52:528–534.
9. Rosas I, McCartney HA, Payne RW, et al. Analysis of the relationships between environmental factors (aeroallergens, air pollution, and weather) and asthma emergency admissions to a hospital in Mexico City. *Allergy*. 1998;53:394–401.
10. Dales RE, Cakmak S, Burnett RT, et al. Influence of ambient fungal spores on emergency visits for asthma to a regional children's hospital. *Am J Respir Crit Care Med*. 2000;162: 2087–2090.
11. Suphioglu C, Singh MB, Taylor P, et al. Mechanism of grass-pollen-induced asthma. *Lancet*. 1992;339:569–573.
12. Walker SM, Panjo GB, Lima MT, et al. Grass pollen immunotherapy for seasonal rhinitis and asthma: a randomized, controlled trial. *J Allergy Clin Immunol*. 2001;107:87–93.
13. Newman-Taylor A. Environmental determinants of asthma. *Lancet*. 1995;345:296–297.
14. Levetin E. Fungi. In: Burge H, editor. *Bioaerosols*. Boca Raton, FL: CRC Press; 1995:87–120.
15. Horner WE, O'Neil CE, Lehrer SB. Basidiospore aeroallergens. *Clin Rev Allergy*. 1992;10:191–211.
16. Horner WE, Helbling A, Lehrer SB. Basidiomycete allergens: comparison of three *Ganoderma* species. *Allergy*. 1993;48: 110–116.
17. Cutten AE, Hasnain SM, Segedin BP, et al. The basidiomycete *Ganoderma* and asthma: collection, quantitation and immunogenicity of the spores. *NZ Med J*. 1988;101:361–363.
18. Levetin E, Van de Water PK. Pollen count forecasting. *Immunol Allergy Clin North Am*. 2003;23:423–442.

19. Burch M, Levetin E. Effect of meteorological conditions on spore plumes. *Int J Biometeorol*. 2002;46:107–117.
20. Holberg CJ, O'Rourke MK, Lebowitz MD. Multivariate analysis of ambient environmental factors and respiratory effects. *Int J Epidemiol*. 1987;16:399–410.
21. O'Rourke MK, Quackenboss JJ, Lebowitz MD. An epidemiological investigating respiratory disease in sensitive individuals to indoor and outdoor pollen exposure in Tucson, AZ. *Aerobiologia*. 1989;5:104–110.
22. Lebowitz MD, Quackenboss JJ, Krzyzanowski M, O'Rourke MK, Hayes C. Multipollutant exposures and health responses: epidemiological aspects of particulate matter. *Arch Environ Health.* 1992;47:71–75.
23. Troutt C, Levetin E. Correlation of spring spore concentrations and meteorological conditions in Tulsa, Oklahoma. *Int J Biometeorol*. 2001;45:64–74.
24. Schappi GF, Taylor PE, Pain MC, et al. Concentrations of major grass group 5 allergens in pollen grains and atmospheric particles: implications for hay fever and allergic asthma sufferers sensitized to grass pollen allergens. *Clin Exp Allergy*. 1999;29:633–641.
25. D'Amato G, Noschese P, Russo M, Gilder J, Liccardi G. Pollen asthma in the deep. *J Allergy Clin Immunol*. 1999;104:710.
26. Burge H. Some comments on the aerobiology of fungus spores. *Grana*. 1986;25:143–146.
27. Solomon WR, Mathews KP. Aerobiology and inhalant allergens. In: Middleton E, Reed CE, Ellis EF, Adkinson NF, Yunginger JW. *Allergy Principles and Practice.* 3rd ed. St. Louis, MO: CV Mosby Co; 1988:312–372.
28. Subiza J. How to interpret pollen counts. *Allergol Immunol Clin*. 2001;16:59–65.
29. Suh HH, Bahadori T, Vallarino J, Spengler JD. Criteria air pollutants and toxic air pollutants. *Environ Health Perspect.* 2000;108(Suppl):625–633.

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