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ORIGINAL PAPER

Short-term effects of pollen species on hospital admissions in the city of Madrid in terms of specific causes and age

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Abstract *Background* In recent years there has been a notable increase in respiratory diseases in industrialised countries, which is attributed to a combination of chemical atmospheric pollution and the allergens existing in the atmosphere of big cities. Few studies, however, have analysed the effect of different pollen species on the different causes of hospital admissions other than those exclusively owing to asthma. *Objective* The aim of this investigation was to analyse the influence of the most abundant pollen species with the highest allergenic potential in Madrid's atmosphere on daily emergency hospital admissions – from all causes and specific causes – according to different age groups. *Methods* An ecological time-series design was adopted in which the effects were quantified using Poisson regression models, taking into account different confusion factors, such as chemical and acoustic atmospheric pollution. *Results* Statistically significant associations were found between pollen species and hospital admissions due to respiratory causes, and between pollen species and all causes of hospital admissions and, to a lesser degree, circulatory causes. The impact was greater in the younger age groups. Concentrations of Poaceae and *Platanus* pollen species were the factors showing the highest correlation to the different causes of admission. *Conclusion* The relative risks analysis revealed a significant effect between the pollen species analysed and health for admitted patients of all age groups; this effect was greater than that detected for the environmental variables traditionally analysed in urban atmospheres.

Keywords Cupressaceae · Hospital admissions · *Olea* · *Platanus* · Poaceae · Pollen · Time-series

Abbreviations

ACF	Simple autocorrelation function
AR	Attributable risk
COPD	Chronic obstructive pulmonary disease
ICD-IX	International Classification of Diseases version 9
PACF	Partial autocorrelation function
RR	Relative risk

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1 Introduction

Various studies have been carried out in the city of Madrid in recent years that have linked emergency hospital admissions with different types of environmental variables. The results of such studies have resulted in analyses of the effects of chemical atmospheric pollution (Díaz et al. 1999, 2001), acoustic pollution (Tobías et al. 2001) and the influence of extreme temperatures (Díaz and Linares 2007) on the health of the general population. A recently published study reports a specific effect of Poaceae on hospital admissions of children (<10 years) and associated the presence of these pollen species to a number of different specific causes of admission (Linares et al. 2006a) has also been described.

Although the influence of different pollen species on hospital admissions has been analysed in a number of studies, these investigations have tended to focus almost exclusively on the exacerbation of asthma cases, both in the child population (Akinbami and Schoendord 2002; Kohonen et al. 2002; Lierl and Hornung 2003) and for all ages (Morrison and McLonne 2001; Galán et al. 2003; Soriano et al. 2003; Ng et al. 2003; Tobías et al. 2003). Moreover, they are generally confounded by the confusion caused by atmospheric pollution sources (Anderson et al. 1998; Dales et al. 2000; Lee et al. 2002), meteorological variables (Newson et al. 1998; D'Amato et al.2001), or both (Lewis et al. 2000; Tobías et al. 2003; Galán et al. 2003). Fewer studies deal with hospital admissions resulting from other respiratory disorders (Thurston et al. 1992; D'Amato 2002; Low et al. 2006), and even fewer evaluate the relationship between pollen concentrations and other specific causes of hospital admissions, such as cardiovascular diseases (Brunekreef et al. 2000; Stieb et al. 2000).

The influence of pollen types upon public health has shown a marked increase in recent times in industrialised countries. This development appears to result from the interaction of airborne pollen with different chemical pollutants existing in big cities (D'Amato 2002), with the possibility that air pollution induces airway mucosal damage and impaired mucociliary clearance, which in turn may facilitate the access of inhaled allergens to the cells of the immune system. Likewise, climate change alters the moment in time and the duration of the period in which pollen and spores are concentrated in the atmosphere as well as the geographic zones in which these allergenic agents appear; as a consequence of this variation, more people will be exposed to pollen species which were heretofore non-existent or which were present in much lower concentrations (Gilmour et al. 2006; McMichael et al. 2006). There is therefore a need to conduct studies that analyse the influence of this greater number of pollen species on the health of the population, taking into account possible interactions with different environmental factors also present in urban atmospheres.

The aim of this was to analyse the short-term effects of the four most abundant pollen types with the highest allergenic potential (Poaceae, *Olea, Platanus*, Cupressaceae) in Madrid's atmosphere (Subiza et al. 1995) on daily emergency hospital admissions due to all causes and to respiratory and circulatory causes, in terms of age groups.

2 Material and methods

2.1 Data on hospital admissions

We recorded the daily number of unscheduled emergency hospital admissions to the Hospital General Universitario Gregorio Marañón, which covers the largest area of Madrid. This hospital records one of the highest numbers of emergency admissions in Madrid. The time period analysed was from January 1, 1995 to December 31, 2000, encompassing a total of 2192 days. The causes analysed were (1) all causes (International Classification of Diseases ver. 9; ICD-IX:1–799), (2) respiratory (ICD- IX:460–519) and (3) circulatory (ICD-IX:390–459) causes; traumatisms and births were excluded. We analysed admissions for all age groups and classified these as under 10 years, 10–17 years, 18–44 years, 45–64 years, 65–74 years and over 75 years.

2.2 Data on pollen species

The data corresponding to daily levels of pollen species were provided by the *Madrid Regional Government's Health Department Palinological Network* (PALINOCAM). We recorded average daily concentration values (grains/m^3) of Cupressaceae, *Olea, Platanus* and Poaceae from the recording station at the Pharmacy Faculty (volumetric method with Burkard samplers).

2.3 Other variables

As control variables that might confound the relationship between hospital admissions and pollen species, we considered all those that had been associated with hospital admissions in the city of Madrid in previous studies. Meteorological variables corresponding to daily maximum, average and minimum temperatures (in °C) were provided by the National Meteorology Institute's Madrid-Retiro Park Observatory. Variables for chemical atmospheric pollution (Díaz et al. 1999, 2001) and acoustic pollution (Linares et al. 2006a; Tobías et al. 2001) were provided by the Madrid City Council's Measurement Network. We thus recorded daily average concentrations of sulphur dioxide, nitrogen dioxide, tropospheric ozone and total particles in suspension ($\mu g/m^3$) and the equivalent levels of daily daytime and nighttime acoustic pollution [dB(A)]. We also gathered information on epidemic periods of influenza from the records of the Compulsory Declaration Disease System.

2.4 Statistical analysis

We first established the type of functional relationship between hospital admissions and the average daily concentrations of the pollen species considered using dispersal diagrams with a lowess-type muting. The dispersal diagrams (scatter-plot) of the different variables were constructed as follows: (1) first, different intervals were established between the minimum and the maximum values of the independent variable; (2) the mean value of each interval was then defined and represented in the *x*-axis; (3) the *y*-axis was used to represent the mean value of the dependent variable (causes of emergency hospital admissions) in the corresponding interval; (4) the points were adjusted by the loess method (SPSS application for performing dispersal diagram; SPSS, Chicago, Ill.).

We then evaluated the lags in which a significant association occurs between hospital admissions and the pollen species with the use of Crossed Correlations Functions between the prewhitened series, eliminating the temporal components relating to trend and seasonality (Campbell and Tobías 2000).

We evaluated the relationship between hospital admissions and the pollen species using Poisson regression models (Schwartz et al. 1996). Apart from the above-mentioned potentially confusing variables, we also used control variables for tendency, sine and cosine functions with periodicities of 90, 120, 180 and 365 days in order to adjust for seasonality and dummy variables for weekdays and holidays. We included the variables in the model according to their individual level of statistical significance by means of the stepwise procedure, and jointly according to the variables minimising Akaike's information criteria (Akaike 1974). Once we had selected the models with the best fit, we used Pearson's residuals to establish the existence of overdispersal and residual autocorrelation by means of simple autocorrelation function (ACF) and partial autocorrelation function (PACF) graphs of the simple autocorrelation functions (Schwartz et al. 1996). We quantified the effects by means of a percentage change of the relative risk (RR) for an increase of 25 grains/m^3 in the concentration of each pollen species.

Lastly, we quantified the potential impact of Poaceae concentrations on public health by means of the attributable risk (AR), defined as AR = (RR−1)/RR (Coste and Spira 1991), for an increase in the concentration of Poaceae defined between the 99th and 95th percentiles, as this concentration can cause epidemic increases in respiratory diseases such as asthma (Tobías et al. 2003). The statistical analysis was conducted with the use of the statistical package S-Plus (Insightful Corp, Seattle, Wash.).

3 Results

During the study period, there were over 126,000 hospital admissions to the Hospital General Gregorio Marañon, with a daily average of 57.6 admissions due to all causes, 11.7 owing to circulatory causes and 9.2 to respiratory causes (Table 1). Table 2 shows the average levels and the distribution of admissions according to percentiles of the pollen species. The temporal distribution of these four species presents a clear seasonal pattern (Fig. 1). The daily concentrations of Poaceae and *Olea* pollen show an annual maximum between the last week of May and the first week of June. For the Cupressaceae, this peak is advanced to the month of February, whereas the annual maximum for *Platanus* pollen occurs at the end of March.

The dispersal diagrams between hospital admissions and pollen species generally show a linear-type relationship, which justifies their inclusion as a linear variable in the regression models. Using the crossed correlation functions we then evaluated the lags in which a significant association occurred between hospital admissions and the pollen species. These lags, which correspond to the pollen species, were included in the regression models, the results of which are shown in Table 3. Of the pollen species studied, pollen of the Poaceae species presented the clearest association with hospital admissions; for example, with an increase of 25 grains/m^3, the risk of emergency admission increased by 1%, whereas for respiratory causes, this risk increased to 2.8%. In terms of age groups, pollen ofPoaceae species again appear to have had the largest effect on hospital admissions, with the risk increasing the greatest in younger patients (1.4% for the over 75 years, 2% for 64–75 and 45–64 years, 4.3% for 10–17 years and 15% for the under 10 years). When the admissions were defined according to specific causes of admission and age groups, Poaceae species pollen had the greatest influence on admissions resulting from respiratory causes, with the risk increasing the most in the younger patients (2% for the over 75 years, 4.7% for 45–64 years, 3.7% for 18–44 years, and 10.2% for 10–17 years). In addition, the association between circulatory causes and pollen species was relevant in patients older than 10 years.

Given the significant influence of Poaceae pollen in relation to hospital admissions, we quantified its potential impact on public health by means of the AR for an increase in the concentration of Poaceae pollen between the 99th and 95th percentiles (101 grains/m^3). Table 4 shows the results of this analysis, and the highest attributable risk is seen to be in admissions due to respiratory causes (AR = 10.4%). According to age, the risk shows a considerable increase in the groups of younger patients (43.2% for the under 10 years for all causes and 32.4% for 10–17 years for respiratory causes).

Table 1 Descriptive analysis of the daily number of emergency hospital admissions at the Hospital General Universitario Gregorio Marañón, Madrid, for the period 1995–2000

	Mean ± SD	Minimum	Maximum
All ages			
Organic	57.6 ± 11.5	25	97
Circulatory	11.7 ± 4.0	1	32
Respiratory	9.2 ± 4.7	0	32
By age groups			
<10 years			
Organic	7.0 ± 3.0	0	21
Circulatory	0.05 ± 0.2	0	2
Respiratory	1.2 ± 1.4	0	10
10–17 years			
Organic	2.1 ± 1.6	0	10
Circulatory	0.3 ± 0.2	0	2
Respiratory	0.1 ± 0.4	0	3
18–44 years			
Organic	11.4 ± 3.7	2	25
Circulatory	0.6 ± 0.8	0	6
Respiratory	1.1 ± 1.1	0	6
45–64 years			
Organic	11.2 ± 3.8	1	27
Circulatory	2.6 ± 1.7	0	10
Respiratory	1.4 ± 1.3	0	8
65–74 years			
Organic	11.1 ± 3.9	1	27
Circulatory	3.4 ± 2.0	0	12
Respiratory	2.1 ± 1.7	0	10
>75 years			
Organic	14.7 ± 5.0	2	37
Circulatory	5.0 ± 2.5	0	15
Respiratory	3.3 ± 2.4	0	20

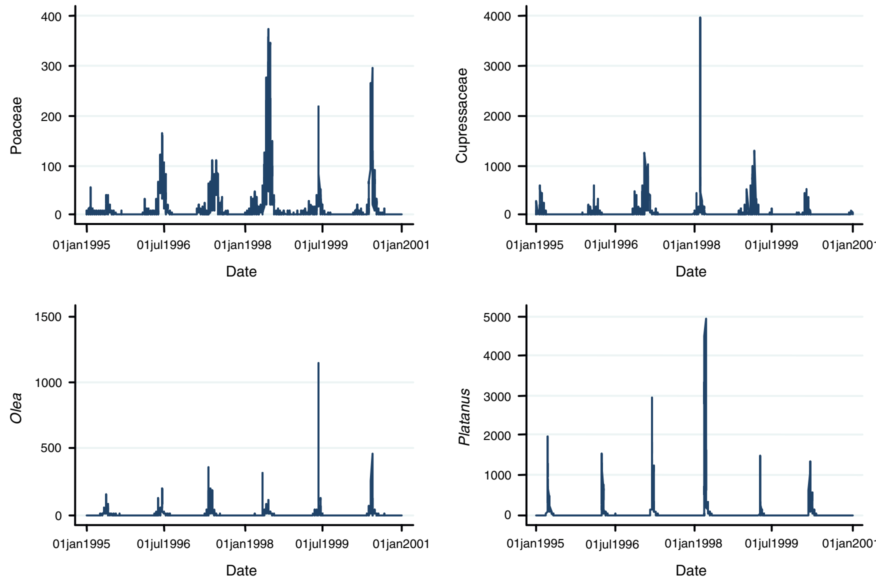
4 Discussion

The distribution of the causes of hospital admissions throughout the study period shows a behaviour

Table 2 Descriptive analysis of pollen levels in Madrid, for the period 1995–2000

Pollen types (grains/m^3)	Mean ± SD	Percentiles					
		Minimum	P50	P75	P95	P99	Maximum
Poaceae	11.9 ± 32.8	0	2	7	63	164	372
Olea	6.7 ± 39.3	0	0	0	31	141	1148
Platanus	43.9 ± 257.4	0	0	0	146	1278	4936
Cupressaceae	32.6 ± 134.1	0	1	9	193	572	3952

Fig. 1 The temporal distribution of pollen species in Madrid (1995–2000)



pattern similar to that described in other studies in that it presents a clear seasonal component. Likewise, the concentrations observed for the pollen species are characteristic of these species for a city like Madrid, and this is demonstrated by the analyses of historic series conducted for the Madrid Regional Government (Gutierrez et al. 2001). The fact that the maximum concentrations of all pollen species considered in this study coincide during the same year appears to be related to the influence on pollination processes of long-term meteorological conditions, such as autumn and springtime precipitation or the number of frost episodes during the previous winter (Díaz et al. 2006). Due to the fact that the series analysed is short, we were unable to detect changes in the pollination periods, such as those suggested by Clot (2003) and Frenguelli et al. (2002), which establish advances in pollination periods of between 0.84 and 0.9 days/year as a consequence of climate change.

All the pollen species analysed in this study were found to have an effect upon hospital admissions in terms of specific causes and for different age groups, but the concentrations of Poaceae and *Platanus* pollen were the most frequently associated with the different causes of admission, thereby confirming the high allergenic capacity of these species, which has been referred to in other studies (Subiza et al. 1994; Anderson et al. 1998; Lewis et al. 2000; Tobías et al. 2003). Practically all of the causes of admissions in all age groups were related to the concentrations of Poaceae pollen. This association was not observed with any of the other environmental variables analysed, which highlights the significant effects of this type of pollen upon human health.

With regard to the lags observed for the different pollen species and the different causes of admission, Poaceae and *Olea* concentrations were found to generally present a short-term effect, between lag 0 and lag 3. Conversely, the effects of *Platanus* pollen concentrations were found to be of the medium to long term (5- to 7-day lags). The magnitude of the effects of the pollen species described in our study is similar to that obtained for chemical-type pollutants associated with hospital admissions in previous studies (Anderson et al. 1998; Lewis et al. 2000; Stieb et al. 2000; Díaz et al. 2001; Linares et al. 2006a).

One of the most relevant results of this study lies in the fact that all of the pollen species considered here were associated with admissions related to circulatory causes, as opposed to respiratory ones. It should be pointed out that few previous studies have associated pollen concentrations in the atmosphere with effects on health due to causes other than respiratory ones (Brunekreef et al. 2000; Stieb et al. 2000). The mechanism by which this effect is achieved resembles that operating for very small-sized particles (<2.5 μm) that are capable of causing pulmonary inflammation, leading to different types of

Table 3 Percentage increase of the relative risk on hospital admissions according to specific causes and group of age (95% confidence interval, 95% CI) for an increment of 25 grains/m^3 in the pollen concentration

	Organic		Circulatory		Respiratory	
	Lag	Percentage (95% CI)	Lag	Percentage (95% CI)	Lag	Percentage (95% CI)
All ages						
Poaceae	2	0.9 (0.4; 1.4)			3	2.8 (1.5; 4.1)
Cupressaceae						
Olea	1	0.4 (0.1; 0.8)	1	0.8 (0.0; 1.5)	1	0.9 (0.0; 1.8)
Platanus	7	0.1 (0.0; 0.1)				
By age group						
<10 years						
Poaceae	2	15.0 (5.1; 25.0)				
Cupressaceae						
Olea						
Platanus					1	3.1 (1.1; 5.1)
10–17 years						
Poaceae	5	4.3 (1.9; 6.6)			1	10.2 (4.8; 15.5)
Cupressaceae						
Olea	3	2.2 (0.8; 3.6)	2	6.9 (1.5; 12.2)		
Platanus					7	0.9 (0.2; 1.5)
18–44 years						
Poaceae					3	3.5 (0.4; 6.6)
Cupressaceae					2	2.8 (1.0; 4.7)
Olea	0	1.0 (0.3; 1.7)				
Platanus			0	0.4 (0.0; 0.8)		
45–64 years						
Poaceae	7	2.0 (1.0; 3.0)			1	4.7 (2.0; 7.3)
Cupressaceae			6	0.5 (0.1; 0.9)		
Olea						
Platanus						
65–74 years						
Poaceae	2	2.0 (1.0; 2.9)				
Cupressaceae						
Olea						
Platanus	0	0.1 (0.0; 0.3)	5	0.3 (0.1; 0.5)		
>75 years						
Poaceae	2	1.4 (1.3; 1.5)	2	1.5 (0.0; 3.1)	3	2.0 (0.0; 4.1)
Cupressaceae	1	0.2 (0.1; 0.2)				
Olea						
Platanus	7	0.1 (0.1; 0.2)	7	1.1 (0.0; 2.1)		

cardiovascular failure. This in turn confirms the relationship found with respiratory diseases other than asthma, such as chronic obstructive pulmonary disease (COPD), pneumonia or bronchitis (Linares et al. 2006a, b). A cohort study has shown that allergic markers such as peripheral eosinophilia and, in individuals with low forced expiratory volume in 1s, positivity on skin-prick test are related to

Table 4 Attributable risk (%) for hospital admissions according to specific causes and age groups for the 95th to 99th percentile increment in Poaceae pollen concentration (101 grains/m^3)

	Organic	Circulatory	Respiratory
All ages	3.5%		10.4%
By age group			
<10 years	43.2%		
10–17 years	15.5%		32.4%
18–44 years			13.0%
45–64 years	7.7%		16.8%
65–74 years	7.5%		
>75 years	5.6%	6.0%	7.8%

increased all-cause mortality as well as mortality due to cardiovascular diseases and COPD (Hospers et al. 1999).

Based on our age group analysis, the effects of pollen concentrations were attenuated with age, with the highest risks found in the youngest age group – the under-10 year olds. This result is in agreement with the particular vulnerability found in children (Landrigan et al. 1999) as this group presents a series of physiological characteristics, such as an immature immune system (Kroll-Smith et al. 2000), a higher respiratory frequency and lower body weight. These latter two characteristics means that they inhale a greater volume of pollutant per body mass unit, resulting in their smaller and narrower airways become inflamed more easily (EPA 2003).

We conclude that, while taking into account the limitations involved in the design of this epidemiological time series, our results suggest the importance of determining the moment in time of the occurrence of the maximum pollination peaks of these pollen species. The attributable risks presented by the pollen species with the higher allergenic capacity were clearly seen to have had an effect on the health of individuals of all age groups. This effect was markedly greater than that of other environmental variables that are traditionally included in this type of study of morbidity in the general population.

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