Air pollution and emergency hospital admissions for cardiovascular diseases in Valencia, Spain

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Abstract

Study objective—To estimate the short-term association between air pollution levels and emergency hospital admissions for cardiovascular diseases in Valencia, within 1994–1996 period.

Design—Daily levels of air pollution and emergency admissions for cardiovascular diseases were related to using an ecological time series design. The number of admissions was obtained from the hospital records database. Selected groups of causes were all cardiovascular diseases, heart admissions, and admissions for cerebrovascular diseases. The number of admissions for digestive diseases was used as control. Pollutants were black smoke, sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO) and ozone (O3). Magnitude of association was estimated by Poisson autoregressive regression. Estimations were calculated according the hottest (May to October) and the coldest (November to April) periods.

Setting—City of Valencia, Spain, about 750 000 inhabitants.

Participants—People being admitted to the two major hospitals in the city, with a catchment area of nearly 400 000 inhabitants.

Main results—For the whole period, a significant association for SO2-24 h was found so a rise in its levels of 10 μg/m³ was associated with an increment of 3% (95%CI 0.4 to 5.7%) in the expected number of cardiovascular admissions. A significant association for black smoke, SO2-24 h, SO2-1 h, and CO-1 h was found in the hottest semester. All these associations were verified with a lag of two days. The estimates of the associations for particles, SO2, and CO were affected by the inclusion of the other pollutants in their models. NO2 was independently associated with cerebrovascular admissions. There were no significant associations between air pollution and admissions for digestive diseases.

Conclusions—Current levels of air pollution and emergency cardiovascular admissions are significantly related in Valencia.

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The impact of air pollution on several outcomes (that is, mortality, respiratory diseases) has been studied in a considerable number of cities throughout the world. Studies on mortality impact of air pollution have shown an association with cardiovascular mortality, however the short-term relation between cardiovascular admissions and urban air pollution has not been assessed until a few years ago. Some studies have been carried out recently in this sense, especially in North America1–7 and also in some cities in northern or western Europe,14–18 in Sydney, Australia,19 and in Hong Kong, China.20 In the Mediterranean area only one study, in Athens,21 has examined this relation.

Most of these time series studies showed an effect predominance of particulates and carbon monoxide (CO) on cardiovascular admissions.1–8 12 14 15 16 17 18 However, the results in some works in Europe14 15 16 and in Sydney19 suggest an independent effect of the nitrogen dioxide (NO2) and sulphur dioxide (SO2). Furthermore, two of the studies in Canada showed a more consistent effect for sulphates’ or for ozone.11

Up to now the effect of air pollution on cardiovascular diseases morbidity has not been assessed in Spain, a country that has a mild climate, different to the climates of most of the other places studied. For this reason it seemed inadequate to extrapolate the results in other parts of the world to our particular environment. Moreover, it has been suggested that weather or, more particularly, temperature may modify the effects of air pollution on health, both high22 and low temperatures.23 Specifically, the results of the latter study, carried out in Chicago, USA suggest that the effect of CO on hospital admissions for heart failure may be temperature dependent, with the magnitude of the effect increasing with decreasing temperature.22 In this sense, laboratory and further epidemiological studies in other cities with different climates are claimed in order to validate that hypothesis. In this study we explore the short-term association between air pollution levels and emergency hospital admissions for cardiovascular diseases in a Mediterranean location, the city of Valencia, Spain, for the period 1994–1996.

Methods

The study was part of an ecological time series one, where daily levels of air pollution and emergency admissions for cardiovascular disease in the two main hospitals of the city of Valencia were related controlling for the major confounding variables.

Setting

Valencia is located on the Mediterranean coast and has a mesothermal climate (mild climate). The air pollution mainly derives from motor vehicles. The city of Valencia, Spain, about 750 000 inhabitants.
vehicle exhaust emissions, with industrial pollution playing a smaller part. The analysis took place in the Hospital Clínico Universitario, and Hospital Universitario La Fe. These hospitals have an urban catchment area of 376,681 inhabitants (total population of the city 750,000 inhabitants). Because both hospitals are part of the public health service network, access to emergency health services is universal. In a previous study we found that people attending a different hospital emergency department for respiratory diseases to their reference one in Valencia represented less than 3% (unpublished data).

**DATA**

**Health measures**

The number of daily admissions was obtained from the registry databases of the two hospitals, being selected the admissions for residents of Valencia city with a primary discharge diagnosis of the following causes (codes of International Classification of Diseases, 9th revision, ICD-9): cardiovascular diseases (ICD-9: 390–459); heart diseases (ICD-9: 410–414, 427, 428); cerebrovascular diseases (ICD 9: 430–438); and admissions for digestive disease excluding vascular related ones (ICD 9: 530–534, 540–543, 560–569, 571–572, 574–578). The latter was selected as a control series. We preferred the use of broad categories rather than more specific ones in order to obtain more precision in results and seeking to reduce likelihood of misclassification.

**Exposure data**

The pollution data were obtained from the city’s air pollution monitoring network, which consists of 14 manual and five automatic monitoring stations. From the manual network the 24 hour average levels for black smoke (reflectometry method) were obtained and from the automatic network the 24 hour average and the one hour maximum levels for NO2 (chemiluminescence), SO2 (ultraviolet fluorescence) and CO (infrared absorption) as well as the eight hours moving average and the one hour maximum levels for ozone (UV absorption). Only the data obtained from those stations with valid readings on more than 75% of days were used in this investigation. The results of this calculation were ruled out if less than 75% of data for that day was available. Using these criteria, seven manual and the five automatic monitoring stations were finally selected. The correlation between the measurements at different stations varied from 0.30 to 0.62 in the manual network (that is, black

| Table 1 Summary of the daily figures for the number of hospital admissions for cardiovascular and digestive causes, the concentrations of air pollutants, the meteorological variables and the flu incidence. Valencia, Spain (1994–1996) |
|-----------------|----------|--------|----------|----------|----------|
| Whole period    | Semesters|        |
|                 | Mean     | Minimum| P50      | Maximum  | n        |
|                 |          |        |          |          |          |
| **Cardiovascular diseases** | 7.0      | 0       | 7.0      | 20       | 1080     |
| **Heart diseases** | 3.9      | 0       | 4.0      | 13       | 1080     |
| **Cerebrovascular diseases** | 1.5      | 0       | 1        | 7        | 1080     |
| **Digestive diseases** | 5.6      | 1       | 5        | 15       | 1076     |
| **Mean temperature (°C)** | 18.7     | 6.6     | 18.4     | 33.8     | 1080     |
| **Relative humidity (%)** | 65.1     | 23.0    | 65.0     | 96.0     | 1080     |
| **SO2 24 h (µg/m3)** | 25.6     | 4.4     | 25.0     | 68.4     | 1073     |
| **NO2 24 h (µg/m3)** | 66.8     | 11.9    | 64.7     | 155.1    | 1072     |
| **NO2 1 h (µg/m3)** | 116.1    | 31.1    | 113.2    | 469.0    | 1072     |
| **O3 8 h (µg/m3)** | 45.9     | 10.2    | 45.0     | 125.0    | 1071     |
| **CO 1 h (mg/m3)** | 6.2      | 0.6     | 5.7      | 17.8     | 1078     |
| **Cases of influenza** | 167.5    | 3.0     | 120.0    | 660.0    | 1080     |

n: number of days with valid observations.

Figure 1 Raw (A) and residual after adjusting for the core model (B) series of the daily number of admissions for cardiovascular diseases in Valencia (1994–1996). Adjusted line: loess with a width of 20%.
cardiovascular admissions and air pollution in Valencia, Spain

Table 2  Pearson correlation coefficients among the environmental variables. Valencia, 1994–1996

<table>
<thead>
<tr>
<th>Variable</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Black smoke</th>
<th>SO2 24 h</th>
<th>NO2 1 h</th>
<th>CO2 1 h</th>
<th>O3 24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>1</td>
<td>0.07</td>
<td>-0.41</td>
<td>-0.42</td>
<td>-0.10</td>
<td>-0.55</td>
<td>0.45</td>
</tr>
<tr>
<td>Humidity</td>
<td>1</td>
<td>0.07</td>
<td>-0.18</td>
<td>-0.10</td>
<td>-0.02*</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td>Black smoke</td>
<td>1</td>
<td>0.63</td>
<td>0.33</td>
<td>0.64</td>
<td>-0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO2 24 h</td>
<td>1</td>
<td>0.22</td>
<td>0.74</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO2 1 h</td>
<td>1</td>
<td>0.03*</td>
<td>-0.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO 24 h</td>
<td>1</td>
<td>-0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O3 24 h</td>
<td>1</td>
<td>-0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

24 h daily average; 1 h: daily one hour maximum level; 8 h daily eight hours moving average maximum level. *p<0.05.

Data of control variables

The daily data for temperature and relative humidity were obtained from Valencia’s meteorological station, located within an urban garden. The weekly influenza cases were taken from the registers of notified diseases. Local holidays and the period of strike action by medical staff during May 1995 were also taken into consideration.

ANALYSIS

Magnitude of association was estimated by Poisson autoregressive regression following the standardised methodology of the APHEA project23–25 with some modifications introduced in the Spanish EMECAM project.26 27 With this approach we assume counts of daily admissions follow a non-stationary overdispersed Poisson process where variations could be explained in part for some factors varying in time (that is, long term trend and seasonality, temperature and humidity, week days, flu incidence, special events, or air pollution). The effect of the former variables must be taken into account to avoid confusion in the estimation of the relation between admissions and air pollution. Therefore, using Poisson regression we analysed data in two steps. Firstly, a core model was built for each outcome variable (that is, the series of daily admissions) controlling for the main confounding variables. Secondly, the association with air pollutants was estimated examining the delayed relation up to the fifth lag of pollutants. To control residual overdispersion serial autocorrelation in the final models autoregressive terms up to the fifth order were checked, including them in the model when significant.

The relation between air pollutants and admissions does not have to be linear. Therefore, besides the linear model, a non-parametric model, including a loess term for the pollutant, has been fitted. This kind of model does not assume any shape of the relation. The departure from the linearity was checked comparing the deviance of both models by means of a $\chi^2$ test with the difference of degree of freedoms between the models.

Furthermore, estimations were calculated for the hottest (May to October) and coldest (November to April) semester. Lastly, to analyse the independence of the associations, two pollutant models were also fitted. The effect of pollution was calculated using the relative risk (RR) corresponding to an increase in 10 µg/m$^3$ in air pollutant indicators (1 mg/m$^3$ for CO).

Table 3  Association between air pollution and the number of emergency hospital admissions for the three groups of cardiovascular diseases and the one of digestive admissions: Valencia 1994–1996. Results expressed as the relative risk (and the 95%CI) in admissions for an increase in the pollutant levels of 10 µg/m$^3$ (1 mg/m$^3$ for CO)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>All cardiovascular diseases L</th>
<th>Heart diseases L</th>
<th>Cerebrovascular diseases L</th>
<th>Digestive diseases L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black smoke</td>
<td>1.0145 (0.999,1.0297)</td>
<td>2.0149 (0.995,1.0349)</td>
<td>2.0156 (0.986,1.0461)</td>
<td>0.9905 (0.957,1.0063)</td>
</tr>
<tr>
<td>SO2 24 h</td>
<td>1.0302 (1.004,1.0568)</td>
<td>2.0137 (1.010,1.0714)</td>
<td>2.0137 (0.984,1.0940)</td>
<td>0.9905 (0.995,1.0518)</td>
</tr>
<tr>
<td>NO2 1 h</td>
<td>1.0065 (0.989,1.0194)</td>
<td>0.9985 (0.998,1.0188)</td>
<td>1.0736 (1.060,1.0867)</td>
<td>0.9790 (0.999,1.0037)</td>
</tr>
<tr>
<td>O3 24 h</td>
<td>0.9905 (0.974,1.0024)</td>
<td>0.9786 (0.953,1.0043)</td>
<td>0.9760 (0.944,1.0060)</td>
<td>1.0095 (0.989,1.0210)</td>
</tr>
<tr>
<td>CO 1 h</td>
<td>1.0077 (0.991,1.0213)</td>
<td>1.0092 (0.995,1.0242)</td>
<td>1.0074 (0.964,1.0107)</td>
<td>0.9937 (0.982,1.0052)</td>
</tr>
</tbody>
</table>

L: lag with the best fit. *NO2-24 h.
As shown in figure 2, in the analysis for semesters some effect modifications were verified. Thus, the association of cardiovascular admissions with black smoke, SO2, and CO was higher in the hottest semester. For the group of all cardiovascular admissions (fig 2A) a significant association for black smoke (RR 10 µg/m³: 1.038; 95% CI 1.011 to 1.067) was found in the hottest semester. It was also found for SO2 24 h (RR 10 µg/m³: 1.050; 95%CI 1.010 to 1.092), for SO2 1 h (RR 10 µg/m³: 1.017; 95%CI 1.002 to 1.032), and for CO 1 h (RR 1 mg/m³: 1.029; 95%CI 1.005 to 1.055). All these estimates were verified for a lag of two days. No significant association was found in the coldest semester. A similar pattern was observed for heart disease admissions (fig 2B).

That is to say, significant associations were found in the hottest semester for black smoke (RR 10 µg/m³: 1.047; 95%CI 1.013 to 1.082), for SO2 24 h (RR 10 µg/m³: 1.054; 95%CI 1.002 to 1.032), and for CO 1 h (RR 1 mg/m³: 1.029; 95%CI 1.000 to 1.058). Lastly, admissions for cerebrovascular diseases presented some different results (fig 2C). The most consistent association was with NO2 24 h at lag 4, with significance in the coldest semester (RR 100µg/m³: 1.037; 95% CI 1.005 to 1.070) and quite similar estimates in the hottest one (RR 100µg/m³: 1.034; 95% CI 0.993 to 1.077). The only significant relation in the hot semester was for CO 1 h (RR 1 mg/m³: 1.064; 95% CI 1.015 to 1.114).

Regarding the two pollutant models they provide changes in some estimates. As can be seen in figure 3 (A and B) the estimations of CO and black smoke associations with admissions for all cardiovascular diseases and for heart disease, respectively, were modified after the inclusion of SO2 in their models. The association of NO2 with admissions for cerebrovascular disease (fig 3C) did not change after controlling for other pollutants. In the stratified analysis by semesters, the two pollutant models yielded a similar pattern to the one provided for the whole period.

Discussion
To our knowledge, this is the first study on the short-term relation between air pollution and emergency hospital admissions for cardiovascular diseases in a Spanish city. Our results suggest that current levels of air pollution and emergency cardiovascular admissions are positive and significantly related in the city of Valencia. Four of the five pollutants studied presented a statistical significant association with cardiovascular admissions. Both black smoke and NO2 were positively associated with cardiovascular admissions. The association was stronger for SO2, although it was only significant for NO2. CO was associated with a lower risk of cardiovascular admissions. This suggests that air pollution may have a short-term impact on cardiovascular admissions.
smoke and SO₂ were more specifically related with heart disease admissions. NO₂ showed a clearer association with cerebrovascular disease, and CO was related with both groups of cardiovascular diseases. The associations with black smoke and CO were significant only for the hottest months. Because of the high correlation between three of the pollutants studied (black smoke, CO, SO₂), it is difficult to assign the potential causal role to an isolated pollutant. Lastly, ozone did not present any significant association with the outcomes.

Particulates (such as PM₁₀₀, black smoke or other indicators), CO and SO₂ are among the pollutants that have been most studied in relation to their cardiovascular impact. Attention has been especially paid to the possibility that the association found among some of these pollutants with cardiovascular admissions was independent of the other pollutants. In table 4 the main results of the revised papers including the same outcomes as our study are shown.

In the majority of studies carried out in North America, results show that SO₂ does not seem to have an independent role in the association with admissions for cardiovascular diseases. Thus, Schwartz and Morris in a study in Detroit, USA, found an independent association of PM₁₀₀ with daily admissions for ischaemic heart disease in people 65 years and older, and no independent contributions of SO₂, CO and ozone for this outcome. CO, as particles, presented an independent association with heart failure admissions. Similarly, in Tucson, USA, where the correlation between particles and SO₂ was low (r = 0.095) Schwartz showed an independent and additive association between both PM₁₀₀ and CO with cardiovascular admissions in people over 65. Simultaneously, Burnett et al, in the 10 major Canadian cities, reported CO as the only gaseous pollutant independently associated with heart failure. In another study carried out by Burnett et al in Toronto, Canada, the apparent association between particles and cardiorespiratory hospitalisation disappeared after adjustment for O₃, NO₂ and SO₂. In Chicago, USA, Morris and Naumova found a strong association of CO with congestive heart disease admissions in elderly people. Finally, Schwartz, in a study in eight US counties (including eastern and western ones) found independent effects (to weather or other pollutants) of PM₁₀₀ and CO on hospital admissions for heart disease in people aged 65 and more.

In contrast, results of the few studies carried out in Europe, are not so conclusive concerning the role of each pollutant. Thus, in London, Poloniecki et al found an association between SO₂ and acute myocardial infarction and all circulatory diseases. For acute myocardial infarction they also obtained positive associations for black smoke, CO, and NO₂, but the most consistent results in the two pollutant models were for SO₂. In Athens, Pantazopoulou et al did not include SO₂ in their study arguing that its levels were low. In the Greek study the magnitude of the association for black smoke, CO and NO₂ with cardiac admissions was of the same order as the one carried out in Valencia.

The results of the European study APHEA, have shown that SO₂ together with the particles contribute to cardiovascular mortality. Furthermore, in this collaborative study, the summary estimates for cardiovascular mortality associated with SO₂ were not substantially altered when particles were also included in the model, confirming that in the cities included in this study SO₂ was more consistent...
than particles were. If SO₂ has any impact on mortality through cardiovascular diseases, it is coherent to think that it can play a part in the triggering of cardiovascular disease. However, in previous studies carried out in Valencia, results have shown a clearer effect of particles on mortality than SO₂22–30 both in all the cause group of mortality and in the circulatory diseases one.

In this study, the two pollutant models showed the complex relation between the air pollution indicators and the outcomes studied. In fact, because of the high correlation between pollution indicators and the outcomes studied, the results shown here are the significant results from single pollutant models.

The results presented here are coherent with the findings of other studies carried out in Valencia on the short-term effect of air pollution on mortality. So, in the context of the Spanish multi-centred EMECAM Project the results for the association between CO and cardiovascular mortality in Valencia31 showed positive and significant estimates for the hottest months (RR for a 1 mg/m³ increase in the daily CO concentration of 1.068; 95% CI: 1.007 to 1.133), which was not found during the rest of the year (RR 1 mg/m³ CO: 0.990; 95% CI: 0.959 to 1.022). In a previous study we found the same pattern of effect modification for SO₂ and total and cardiovascular mortality: its relation was significant in the hot period but not in the cold one.32

In some other Mediterranean cities the risk estimates for the relation between air pollution and mortality were higher in the warmer season.31,32 Besides the potential for biological interaction between air pollution and mortality, other possible explanations have been argued. One derives from the fact that during the warmer months people could modify their activity patterns.33 This includes people spending more time outdoors and windows being left open for longer, so the actual exposure could be more correlated with outdoor concentrations. Another reason could be that, during the warmer period, other stronger determinants of daily mortality and morbidity (such as acute respiratory infections) are less influential.32

Lastly, one local potential reason for this pattern could be that the climate in Valencia is very mild, without extreme cold temperatures. In fact, the lowest daily average temperature registered during the study period (6.6°C) was superior to the cut point for stratification corresponding to the lowest temperature strata analysed in Chicago (4.4°C) for the daily maximum temperature.34 That is to say, it is difficult to have an interaction between air pollution and low extreme temperatures because they almost do not exist in Valencia.

### Table 4 Results from articles studying the association between cardiovascular hospital admissions and air pollution

<table>
<thead>
<tr>
<th>Author/s (year of publication)</th>
<th>Site</th>
<th>Outcome</th>
<th>Pollutant</th>
<th>Increase (%) in admissions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schwartz J and Morris R⁶</td>
<td>Detroit, USA</td>
<td>Ischaemic heart disease</td>
<td>PM10</td>
<td>0.6</td>
</tr>
<tr>
<td>Schwartz J⁹</td>
<td>Tucson, USA</td>
<td>All cardiovascular</td>
<td>PM10</td>
<td>1.8</td>
</tr>
<tr>
<td>Burnett R et al⁸</td>
<td>Toronto</td>
<td>Heart disease</td>
<td>Sulphates</td>
<td>2.1</td>
</tr>
<tr>
<td>Schwartz F¹</td>
<td>eight counties USA</td>
<td>All cardiovascular</td>
<td>PM10</td>
<td>1.0</td>
</tr>
<tr>
<td>Polonecki JD et al⁶</td>
<td>London, UK</td>
<td>All cardiovascular</td>
<td>BS</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SO₂</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NO₂</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CO</td>
<td>2.1</td>
</tr>
<tr>
<td>Wordley J et al⁴</td>
<td>Birmingham, UK</td>
<td>All cardiovascular</td>
<td>PM10</td>
<td>2.1</td>
</tr>
<tr>
<td>Morgan G et al¹⁸</td>
<td>Sydney, Australia</td>
<td>Heart disease</td>
<td>PM10</td>
<td>0.8</td>
</tr>
<tr>
<td>Wong T et al²⁰</td>
<td>Hong Kong, China</td>
<td>All cardiovascular</td>
<td>PM10</td>
<td>0.6</td>
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<td></td>
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<td>SO₂</td>
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<td></td>
<td></td>
<td>NO₂</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₃</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Results expressed as the increase (%) in admissions for an increase in the pollutant levels of 10 μg/m³ (1 mg/m³ for CO). The results shown here are the significant results from single pollutant models.
Our data provide some indication of an independent association between NO$_2$ and hospitalisations for cerebrovascular disease. The correlation of NO$_2$ with weather and other pollutants in Valencia is low, and daily level series of NO$_2$ did not show a defined seasonal pattern. Furthermore, the estimates of the association did not change after adjusting for other pollutants. All this supports the idea that these results are not confounded for other factors varying in time.

In contrast with cardiac disease, the relation between air pollution and cerebrovascular diseases has been explored in only a few studies. Pönka and Virtanen reported in Helsinki$^{15}$ a similar relation between NO$_2$ and cerebrovascular diseases than the one found in Valencia. In a study in Birmingham only including PM10 as air pollution indicator, Wordley et al$^{7}$ showed an association of particulates with admissions for cerebrovascular diseases and not with other cardiovascular disease groupings. In another paper studying this diseases’ group, Poloniecki et al$^{8}$ did not find any evidence of its association with black smoke, ozone, NO$_x$, SO$_2$, or CO, but it could be relevant to mention that these authors only explored the first lag of pollutants. In Hong Kong, China, Wong et al$^{16}$ showed a significant relation of NO$_2$, O$_3$, SO$_2$, and PM$_{10}$ with hospital admissions for cardiovascular diseases. In their analysis for specific causes ischaemic heart disease and cerebrovascular diseases were not significantly associated with any of the pollutants; however NO$_2$ showed the highest effect with cerebrovascular diseases (RR for an increase of 10 µg/m$^3$: 1.008, 95%CI 0.998 to 1.018).

In a considerable number of studies, ozone has been linked with respiratory toxicity including increase of mortality,$^3$ emergency respiratory visits,$^3$ and hospital admissions for respiratory morbidity.$^11$ $^{12}$ In Valencia we have described such a significant association with emergency visits for asthma$^37$ and for chronic obstructive pulmonary disease.$^16$ However, there is little evidence of an association between ozone and cardiovascular morbidity. Our results do not suggest an impact of ozone on the number of hospitalisations attributable to cardiovascular disease. These results agree with those obtained in other studies$^6$ $^8$ $^{10}$ $^{12}$ $^{13}$ $^{19}$ in that all of them did not find an association with cardiovascular hospital admissions. Only three of the studies reviewed showed evidence of a consistent association between ozone and cardiovascular admissions. In the study of Burnett et al in Toronto,$^{11}$ ozone was the most clearly and strongly associated with hospitalisation for cardiac diseases in summer. In the study of Pönka and Virtanen in Helsinki,$^{15}$ ozone, besides nitric oxide, was the most clearly associated pollutant with the number of emergent admissions for ischaemic cardiac diseases. Lastly, Wong et al$^{16}$ in Hong Kong, found a significant relation of O$_3$ with hospital admissions for cardiovascular diseases.

In contrast, Prescott et al$^{18}$ found a negative association of O$_3$ with cardiovascular admissions in ages over 65. The authors argued that, because of the complex relation between O$_3$ and NO and NO$_2$, their central estimate at the fixed sampling point could provide an inaccurate reflection of the actual exposure for most of the population. This fact may have happened in other cities where studies of the effect of ozone on health have been carried out. Because it is a secondary pollutant, generated from precursors such as nitrogen oxide and volatile organic compounds through exposure to solar radiation, it reaches its concentration maximum far from the emitting focus (mainly traffic). For that reason, to evaluate the impact of ozone on health more precisely, it would be suitable to have monitoring stations located in peripheral areas where the population is likely to be exposed to the highest levels of ozone.$^{39}$

In the past years a great advance has been made concerning the possible biological mechanism of the impairment of air pollution in cardiovascular health. Results of studies that have explored the possible physiopathological mechanisms have given evidence that fine particulates in suspension can lead to systemic effect, such as an increase of plasma viscosity$^{10}$ or heartbeat alterations.$^{41}$ Toxicological studies have found biological alterations in rats after exposure to filtered air or concentrated ambient particulate matter.$^{42}$ Abnormalities in the electrocardiogram after exposure to fine particles have also been found in dogs.$^{43}$

The possible role of CO in causing cardiovascular disease has been investigated for many years.$^{14}$ People occupationally exposed to high levels of CO presented high risk of arteriosclerosis heart disease.$^{15}$ But even exposure to low doses of CO can produce significant effects on cardiac function during exercise in subjects with coronary artery disease, as showed by Allred et al.$^{44}$ $^{45}$

The physiopathological mechanisms of SO$_2$ and NO$_2$ causing cardiovascular damages are insufficiently understood, and more research is needed in this way. Probably these pollutants, as also particles and CO, could play a part among other not yet studied components of air pollution as sulphates or volatile organic aerosols from automotive or other sources.

The use of a database designed for other means may have a limited application in other different fields. In the case of time series epidemiological studies, the key aspects would be exhaustivity of registers, perseverence of specific clinical information and the fulfillment of

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**KEY POINTS**

- Current levels of air pollution and emergency cardiovascular admissions are significantly associated in Valencia.
- The independent effect of some correlated pollutants (that is, particles, SO$_2$, and CO) is difficult to evaluate, as they represent proxies of the quality of ambient air.
- NO$_2$ could play a part in the development of cerebrovascular diseases; this hypothesis needs further investigation.
date variable.46 The hospital database quality of Valencia Community has been analysed showing very few errors in the administration variables, except for the residence.47 This problem may result in a misclassification bias, which would be non-differential in any case, as it does not seem logical for patient residence data errors to be connected with daily atmospheric pollution levels. On the other hand, a study carried out in Canada48 showed a good agreement (k index: 0.84) in the classification of visits attributable to heart disease, and there was no evidence of diagnostic bias in relation to daily pollution levels.

In conclusion, these results add more evidence to the knowledge about the impact of air pollution on cardiovascular health, in this case in a Spanish Mediterranean city, a different climate to the ones already studied. Results show that an increase in pollution levels attributable to SO₂ black smoke or CO are associated with an increase in the number of emergency admissions for heart diseases in Valencia. Furthermore, an association between environment levels of NOₓ and the number of urgent admissions for cerebrovascular diseases has been found, although this aspect needs further investigation to enable adequate quantification. Moreover, the results presented here are coherent with previous studies on mortality carried out in Valencia. These evidences of preventable disease linked to air pollution must be a key element in the process of decision making related with public health policies.

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