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Air pollution and neonatal deaths in São Paulo, Brazil

C.A. Lin[1], L.A.A. Pereira[1], D.C. Nishioka[1], G.M.S. Conceição[1], A.L.F. Braga[1,2] and P.H.N. Saldiva[1]

[1]Laboratório de Poluição Atmosférica Experimental, Departamento de Patologia (LIM 05), Faculdade de Medicina, Universidade de São Paulo, São Paulo, SP, Brasil
[2]Programa de Pediatria Ambiental, Departamento de Pediatria, Faculdade de Medicina, Universidade de Santo Amaro, São Paulo, SP, Brasil

Abstract

Air pollution has been associated with health effects on different age groups. The present study was designed to assess the impact of daily changes in air pollutants (NO_2, SO_2, CO, O_3, and particle matter (PM_{10})) on total number of daily neonatal deaths (those that occur between the first and the 28th days of life) in São Paulo, from January 1998 to December 2000, since adverse outcomes such as neonatal deaths associated with air pollution in Brazil have not been evaluated before. Generalized additive Poisson regression models were used and nonparametric smooth functions (loess) were adopted to control long-term trend, temperature, humidity, and short-term trends. A linear term was used for holidays. The association between air pollutants and neonatal deaths showed a short time lag. Interquartile range increases in PM_{10} (23.3 µg/m^3) and SO_2 (9.2 µg/m^3) were associated with increases of 4% (95% CI, 2-6) and 6% (95% CI, 4-8), respectively. Instead of adopting a two-pollutant model we created an index to represent PM_{10} and SO_2 effects. For an interquartile range increase in the index an increase of 6.3% (95% CI, 6.1-6.5) in neonatal deaths was observed. These results agree with previous studies performed by our group showing the deleterious effects of air pollutants during the perinatal period. The method reported here represents an alternative approach to analyze the relationship between highly correlated pollutants and public health problems, reinforcing the idea of the synergic effects of air pollutants in public health.

Correspondence
C.A. Lin
Laboratório de Poluição Atmosférica Experimental
Departamento de Patologia, FM, USP
Av. Dr. Arnaldo, 455
01246-903 São Paulo, SP
Brasil
E-mail: calin@uol.com.br

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Key words
- Neonatal mortality
- Infant mortality
- Air pollution

Introduction

Air pollution has been positively associated with several adverse outcomes in public health for different age groups. Several studies have indicated that aged people as well as the children's populations are more sensitive to both the acute and chronic adverse effects of air pollution (1-14).

For children, the adverse effects of air pollution seem to affect different periods of their lives. In São Paulo, air pollution exposure has been associated with mortality due to respiratory diseases among children under 5 years of age (15,16). Braga and colleagues (12) and Lin and colleagues (13) found a strong association between air pollution and hospital admissions due to respiratory problems for children and adolescents younger than 13 years. Analyses stratified by age group showed that the strongest effects occur among infants (17).

Using a retrospective cohort study, Woodruff and colleagues (18) demonstrated an association between air pollution, mainly particle matter (PM_{10}), and postneonatal mortality in the USA.

Other studies have shown that the effects of air pollutants can start as early as during pregnancy. Ritz and colleagues (19,20) investigated the birth outcomes due to air pollution in California, USA, and found a positive association between air pollution and both birth defects (19) and preterm birth (20). Wang and colleagues (21) and Bobak and Leon (22) reported associations between air pollutants and low birth weight. Also, Pereira and co-workers (23) demonstrated a positive association between intrauterine death and air pollution. This last investigation, a pioneering one in Brazil, is relevant because it clearly shows that an increase in the level of air pollutants is associated with late fetal loss, raising questions about the possible association between air pollution and neonatal outcomes.

The results of these studies have suggested that the younger the subjects the stronger the health effects of air pollution.

In order to test this hypothesis, we carried out a time series study evaluating the daily air pollution exposure and total neonatal mortality in São Paulo between 1998 and 2000.

Material and Methods

The Municipal Mortality Information Improvement Program (PROAIM) provided daily counts of total neonatal deaths (up to 28 days after birth) in the city of São Paulo from January 1998 to December 2000.

The São Paulo State Sanitary Agency (CETESB) provided daily records of NO_2, SO_2, CO, O_3, and PM_{10} concentrations (24). The pollutant levels recorded at each station were averaged and considered to be indicative of the citywide status. Information on daily minimum temperature and relative humidity was provided by the Institute of Astronomy and Geophysics of the University of São Paulo (IAG-USP).

Statistical modeling was done using Poisson regression techniques in generalized additive models, which are widely employed in time-series studies investigating the effects of air pollution on public health (7). Daily number of neonatal deaths was used as the dependent variable in the models and locally weighted running line smoother (loess), a nonparametric function, was used to control for time (long-term trend), temperature, humidity, and days of the week, assuming a nonlinear behavior of these parameters. A linear term was used for holidays. Our basic model was defined as follows:

$$\mathrm{Log}[\mathrm{E}(ND)] = \alpha + S_{\mathrm{time}} + S_{\mathrm{temperature}} + S_{\mathrm{humidity}} + S_{\mathrm{dow}} + ß_{\mathrm{holidays}} + ß_{\mathrm{pollutant}} \quad (1)$$

were *ND* is the daily count of neonatal deaths and E(*ND*) is the expected value of that count, *S* is the nonparametric smooth function and ß is the regression coefficient of linear terms. Autoregressive terms were included in the models when the analysis of the autocorrelation plots indicated the necessity of minimizing the autocorrelation of the residuals.

The effect of air pollutants was estimated using the air pollutant levels on the concurrent day and moving averages from two to seven days in single-pollutant models. Co-pollutant models were adopted for those pollutants that presented a positive and statistically significant association with the outcome in single-pollutant models. The high correlation between primary pollutants and their mixture in outdoor air makes it difficult to accept that adverse effects may be attributed to a single pollutant. An index of air pollution was created with the pollutants included in the co-pollutant models, an approach already used in a previous study by our group (23). The index was defined as follows:

$$\text{Index} = \frac{\dfrac{\text{pollutant}_1}{\mu_1} + \dfrac{\text{pollutant}_2}{\mu_2} + ... + \dfrac{\text{pollutant}_p}{\mu_p}}{p} \quad (1)$$

where p is the number of pollutants and μ is the mean value of the pollutant concentration during the study period.

The results are reported as percent increase in neonatal deaths due to interquartile range increases in air pollutant levels. The 95% confidence intervals were estimated assuming normal distributions of the residuals.

Results

Descriptive measures (mean, standard error, minimum and maximum values, and the number of days during the study period for which information was available) of the variables under investigation are shown in Table 1. Data were available for all days during the study period and all pollutants showed lower daily mean levels compared to their primary standards.

Table 2 presents the pairwise Pearson correlation coefficients between the pollutants and meteorological variables. In general, primary pollutants correlated strongly with each other and PM_{10} presented the highest correlations. O_3 presented a negative correlation with CO but low and positive correlations with the other primary pollutants ($r \leq 0.4$). Humidity was correlated inversely with all pollutants, while, as expected, minimum temperature was negatively correlated with primary pollutants but not with O_3.

Table 3 presents the estimated regression coefficients and standard errors of pollutants using single-pollutant models and one co-pollutant model with PM_{10} and SO_2, those

Table 1. Descriptive data for the main variables used in the analysis.

	Daily mean ± SEM	Minimum	Maximum
Neonatal daily deaths	6.11 ± 0.08	0	17
Pollutants			
NO_2 (µg/m^3)	94.57 ± 42.36	23.52	308.91
SO_2 (µg/m^3)	15.32 ± 8.25	2.26	71.47
CO (ppm)	2.83 ± 1.38	0.54	10.25
PM_{10} (µg/m^3)	48.62 ± 21.18	13.93	157.27
O_3 (µg/m^3)	76.11 ± 40.69	11.88	280.48
Weather variables			
Temperature (°C)	15.10 ± 3.53	-0.20	23.20
Relative humidity (%)	80.30 ± 8.70	45.67	96.58

Number of days = 1096.

Table 2. Pairwise Pearson correlation coefficients between pollutants and meteorological variables.

	CO	NO_2	SO_2	PM_{10}	O_3	Minimum temperature	Humidity
CO	1.00						
NO_2	0.67*	1.00					
SO_2	0.55*	0.68*	1.00				
PM_{10}	0.71*	0.76*	0.80*	1.00			
O_3	-0.03	0.33*	0.29*	0.36*	1.00		
Minimum temperature	-0.10*	-0.09*	-0.33	-0.23*	0.08	1.00	
Humidity	-0.37	-0.36	-0.48	-0.56	-0.31	0.84	1.00

*P < 0.05.

Table 3. Estimated regression coefficients and standard errors for concurrent day pollutant concentrations using single-pollutant and co-pollutant models, and the index combining PM_{10} and SO_2, controlling for seasonal trends, holidays, and weather variables.

	Coefficients and standard errors		
	Single-pollutant	Co-pollutant (PM_{10} and SO_2)	Index (PM_{10} and SO_2) (%)
PM_{10}	0.0017 (0.0008)	0.0000 (0.0011)	0.1178 (0.0036)
SO_2	0.0063 (0.0019)	0.0063 (0.0025)	–
NO_2	0.0005 (0.0003)	–	–
CO	0.0061 (0.0110)	–	–
O_3	0.0004 (0.0003)	–	–

which presented statistically significant associations with daily neonatal deaths in the single-pollutant models, and for the index created by us to represent both the effects of PM_{10} and SO_2. The effects of PM_{10} and SO_2 showed the best correlation coefficients when the concurrent day concentrations were used. Thus, we included in Table 3 the estimates of concurrent day levels for all pollutant terms analyzed. When both PM_{10} and SO_2 were included simultaneously in the model, only SO_2 remained significant. The index for PM_{10} and SO_2 showed the strongest association with neonatal daily deaths.

The percent increases in daily neonatal deaths due to interquartile range increases in PM_{10}, SO_2, and index concurrent-day levels are presented in Figure 1. The acute effects attributed to usual variations in pollutant concentrations ranged from 4 to 6%.

Discussion

The problem of air pollution and adverse outcomes in public health has been repeatedly investigated. Although the adverse effects of air pollution on public health have been consistently pointed out, several fields deserve additional investigation. Preterm birth and low birth weight associated with air pollution have been extensively studied (20-22) and both conditions may possibly lead to neonatal death. Thus, neonatal daily deaths associated with daily changes in pollutant levels are a subject worth exploring.

The present study reports adverse health effects attributed to the exposure to the air pollutants such as increases in neonatal deaths that have not been explored before. In Brazil, neonatal deaths are events correlated with perinatal assistance more than with environmental factors (25). The associations reported in the present study were robust enough to resist modeling for the most usual confounding factors used in ecological time-series studies of the adverse health effects of air pollution. Since the adopted endpoint is not usual, it is possible that some specific confounder may have been missed. Nevertheless, the lack or the poor quality of perinatal care are factors that cannot confound the association presented in this study because they do not show daily or even seasonal variations. Also, our results were estimated using 95% confidence intervals, which minimizes the possibility of the effects having occurred by chance. Two pollutants (PM_{10} and SO_2) were found to have consistent associations with daily neonatal deaths. Both pollutants were highly correlated with each other and have been associated with adverse respiratory health effects on children in our previous studies (12,13,17).

Despite differences in age and outcomes, our study agrees with those by Braga et al. (17) and Bobak and Leon (26). Both showed associations between PM_{10} and SO_2 with increased morbidity and mortality among infants.

The creation of an index containing both PM_{10} and SO_2 allowed the observation of their cumulative effects on the daily death counts, a situation closer to the natural scenario. Associating highly correlated pollutants is a useful procedure that provides a better estimate of their effects and that has been applied elsewhere by us to estimate the compound effects of air pollutants in São Paulo (23).

The scenario of air pollution represents a particular situation in the metropolitan area of São Paulo. As occurs in Los Angeles, CA, USA, and in most of the large metropolitan

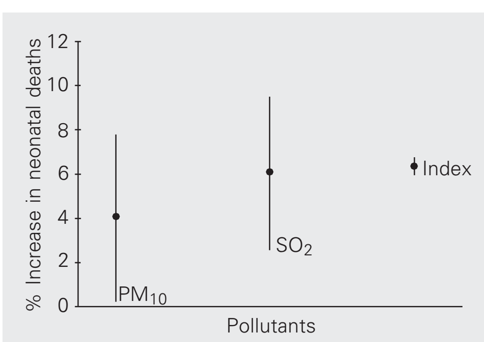

Figure 1. Increases in neonatal deaths due to interquartile range increases of PM_{10} (23.3 μg/m^3) and SO_2 (9.2 μg/m^3) levels, and the PM_{10} and SO_2 index (0.52 μg/m^3) on the concurrent day.

regions of the world, the main source of air pollution in São Paulo is the fleet of almost 6,000,000 vehicles. While fossil fuel is practically the only one used in the other cities, in São Paulo fuels of different origins are used, such as fossil, ethanol, a mixture of gasoline (80%) and ethanol (20%), and methane gas. The complex mixture of pollutants resulting from the combustion of different fuels may induce a unique and perhaps more severe susceptibility of certain population groups to air pollution, maximizing the adverse effects and permitting their better assessment.

In Brazil, PROCONVE, a national program, has been in effect since the mid-1980's to control air pollutant emissions from vehicles. Moreover, both the State Government and City Council of São Paulo have adopted other restrictive measures since 1995 in order to reduce the number of daily circulating automobiles. Together, these procedures have consistently and progressively reduced the levels of pollutants. The present study showed a consistent association between neonatal deaths and air pollution, indicating that current air pollution levels are still associated with the deleterious effects on public health. Although it is expected that population morbidity and mortality may improve when pollutant levels consistently fall, for neonates, more sensitive than adults to the effects of air pollution, the desired levels of air contamination have not yet been reached. It is clear that more consistent restrictive measures against air pollution should be adopted.

The short time lag between the increases in pollutant levels and the increases in neonatal deaths suggests that the effects of the pollutants were consistent and directly influenced neonatal deaths. We do not have enough information to conduct an analysis of cause-specific neonatal deaths. Probably most of them are due to respiratory problems, explaining the acute effects.

This study contributed to the epidemiological investigation of the effects of air pollution on children's health, expanding susceptible age groups and outcomes and showed that the size of air pollution-associated disease burden is still unknown.

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