Effect of atmospheric pollution on the respiratory system*

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Santiago de Chile has a high level of air pollution with ozone (O_3), carbon monoxide (CO) and particles equal or smaller than 10 μm (PM_{10}) usually exceeding the accepted standards. This situation should be noxious for the exposed population and particularly –in the case of O_3 and PM_{10}– for the respiratory system. However, such an effect is rather difficult to demonstrate and it depends on the type of population under study.

Key words: *atmospheric pollution, lung infections, respiratory adverse effects, wheezing bronchitis*

INTRODUCTION

The spectrum of biological response to contaminant exposure might be considered as a continuum that initiates with organic storage of contaminants, biochemical changes and other modifications of uncertain significance. The process may, or may not, end in evident noxious effects on health: physiological changes, morbidity and mortality, the latter being the top of a pyramid of which the basement represents the total affected population.

The adverse respiratory effects ascribed to air pollution (American Thoracic Society, 1985, 1996) include the whole spectrum referred to above. Starting with altered host defense (mucociliary clearance and macrophage function), it may lead to decreases in lung function, airways reactivity and bronchial asthma exacerbation or increases in respiratory illness, lung inflammation, health care utilization and cardiorespiratory mortality. The evidence linking these effects to specific atmospheric pollutants (Table I) comes from the fields of toxicology and epidemiology (American Thoracic Society, 1996). In some cases, the mechanisms of such adverse respiratory effects are not well understood, for example, the excess of morbidity and mortality associated with increases in PM_{10} (American Thoracic Society, 1996).

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Table I

Adverse effects of air pollutants* on respiratory system

Pollutant	Immediate or short term effects	Long term effects
PM_{10}	Increase in respiratory morbidity and mortality Decrement in lung function Interference with pulmonary defense mechanisms	Chronic bronchitis Genotoxicity (?) Lung cancer (??)
O_3	Decreased FVC and FEV_1 Alveolitis (BALF) Bronchial obstruction Bronchial hyperresponsiveness	Unknown
SO_2	Bronchial obstruction Bronchial hypersecretion (in healthy and especially in asthmatic people)	Chronic bronchitis
NO_2	Bronchial hyperresponsiveness Increase of respiratory morbidity (infants and children) Pulmonary edema and fibrosis (in high concentrations) Decrease of mucociliary clearance	Unknown

FVC: forced vital capacity; **FEV_1:** forced expiratory volume in first second; **BALF:** broncho-alveolar lavage fluid showing an inflammatory reaction

* Being an important atmospheric contaminant, CO was not considered here, since its effects on the respiratory system are only indirect (interference in hemoglobin oxygen transport and cytochrome oxidase activity).

AIR QUALITY OF SANTIAGO DE CHILE

Santiago, the capital of Chile, an extended city with nearly 4.5 million inhabitants, is located 33°27'S, 70°41'W. Since its installation (1978), Santiago's public monitoring network detects airborne particulate matter (PM) levels exceeding the annual geometric average standard (75 $\mu g/m^3$) (Cárdenas, 1991). During winter and fall, the air of Santiago is polluted with particles smaller than 10 µm in aerodynamic diameter (PM_{10}), exceeding largely the standard. Carbon monoxide (CO) concentrations exceed the standard of quality (9 ppm/8 h or 10,000 $\mu g/m^3$/8 h) in all but one of the network's stations, especially around traffic peak hours. Ozone (O_3) has exceeded the standard (80 ppb/h or 160 $\mu g/m^3$/h) in all the stations, particularly in spring and summer, and in north and east city zones. Neither SO_2 nor NO_2 exceed the annual standards of quality (80 and 100 $\mu g/m^3$, respectively) (Cárdenas, 1991). During 1995, the maximal values registered for PM_{10}, CO and O_3 exceeded two times or more the respective standards. That year, according to SESMA (Environmental Health Service for Metropolitan Region), the PM_{10} and CO were over the standards for 60 days, whilst O_3 exceeded its standard during more than 150 days (CONAMA, 1997).

CHEMICAL COMPOSITION OF SANTIAGO's PM_{10}

Studies have shown the presence of organic as well as inorganic compounds in Santiago's PM_{10}. Among the organic compounds, high levels of polycyclic aromatic hydrocarbons (PAH) have been found (arenes and nitroarenes) which exhibit mutagenic activity *in vitro* (Gil *et al*, 1991). With regard to the inorganic matter, the presence of anthropogenic inorganic compounds, such as lead, was detected in particles smaller than 3 µm in aerodynamic diameter (Préndez *et al*, 1991). Natural elements, such as iron, were found in larger particles.

Lately, we have compared the inorganic compounds of airborne particulate matter from Santiago and San Felipe, the latter as a control city (Oyarzún *et al*, 1996). San Felipe, with a population of *ca.* 48,000 inhabitants, is located 90 km North-East from Santiago. We analyzed 80 samples of

particulate matter collected during July and August 1993 from two monitoring stations in Santiago (station A: Plaza Gotuzzo, n = 20; station B: Providencia/Seminario, n = 20) and one from San Felipe. Anions, quantified by ionic chromatography and capillary electrophoresis, were detected only in $PM_{2.5}$ fraction. Chlorides, sulphates and nitrates concentrations were higher in Santiago than in San Felipe (Table II). Metals were determined by atomic absorption spectrometry. Mean concentrations of zinc, copper, iron and lead in PM_{10} were substantially higher in Santiago than in San Felipe. Cadmium and manganese were detected only in Santiago's samples, while molybdenum was undetected in both cities (Fig 1). As expected, the PM_{10} in Santiago contains more anthropogenic anions and metals than in San Felipe.

Table II

Mean PM_{10} level and anion concentrations in Santiago and San Felipe

Stations	PM_{10} (μg/m³)		Anions (μg/m³)		
	July	August	Cl^-	NO_3^-	$SO_2^=$
Santiago A	178	146	1.8	5.3	10.7
Santiago B	156	139	0.3	1.7	5.2
San Felipe	69	90	0.1	0.5	2.0

SHORT TERM PULMONARY RESPONSE TO SANTIAGO's AIR POLLUTION IN CHILEAN SCHOOLCHILDREN

We conducted a study to determine if Santiago's air pollution increases the incidence or severity of bronchial hyperresponsiveness (BHR) or interferes with pulmonary function (Ancic *et al*, 1994; Oyarzún *et al*, 1993). Two cohorts of healthy non-smoking school children were followed over two years. The exposed cohort (n = 146) was recently arrived in Santiago from non-polluted areas, while the control group (n = 162) lived in San Felipe, an unpolluted city with similar meteorological conditions to Santiago. Contaminant levels (PM_{10}, O_3 and SO_2) and climatic variables were continuously measured in both cities. In Santiago, we used the data obtained from the monitoring network. In San Felipe, a monitoring station was installed in the yard of one of the participating schools. In San Felipe, the contaminant's levels never surpassed the accepted standards, while the levels of PM_{10}, CO and O_3 in Santiago frequently exceeded the standards (Table III).

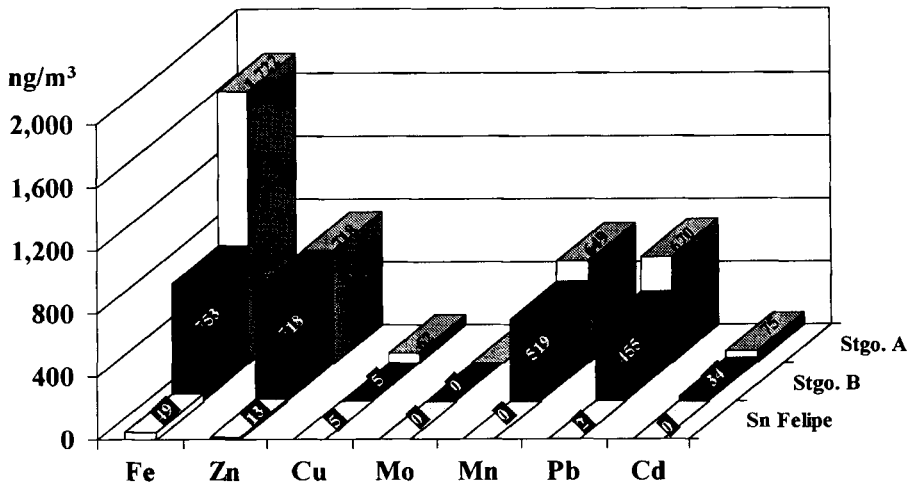

Fig 1. Metals concentrations of fine particulate airborne matter from Santiago (Stgo) and San Felipe. Each column represents the geometric mean. Stgo A: Plaza Gotuzzo monitoring station. Stgo B: Seminario/Providencia monitoring station.

Table III

Contaminants levels in Santiago and San Felipe (1993)

Contaminants	Chilean standards *	Mean values			Times exceeding standards		
		Santiago**		San Felipe	Santiago**		San Felipe
O_3	80 ppb/1 h	13	26	24	13	125	0
PM_{10}***	150 µg/m^3/24 h	110	116	70	52	66	0
CO	9 ppm/8 h	–	–	–	442	631	0
SO_2	140 ppb/24 h	11	17	4	0	0	0
NO_2	160 ppb/24 h****	23	30	–	0	0	0

* Expressed in µg/m^3, reference values for O_3, CO, SO_2 and NO_2 correspond to 160, 10000, 360 and 300, respectively.
** Measurements from two included stations of monitoring system, nearest to participating schools.
*** PM_{10}: particles with < 10 µm aerodynamic diameter.
**** Reference value from USA.
SOURCE: SESMA's air pollution measurements summary, 1993.

Spirometry and bronchial hyperresponsiveness (BHR), measured through a methacholine provocation test (Chai *et al*, 1975), were assessed at baseline and at 6 and 21 months of follow up. BHR was defined, according to Cockcroft *et al* (1977), by a PC_{20} (concentration of methacholine causing 20% fall in FEV_1) equal or lower than 8 mg methacholine/ml. Allergic condition (Prick test) and indoor pollution (questionnaire) were also assessed. Both cohorts (Santiago *vs* San Felipe) were similar in terms of age (13.6 ± 0.9 *vs* 13.2 ± 1.0 years old), gender (males: 47.0 *vs* 42.1%) and height (156.1 ± 8.5 *vs* 152.0 ± 8.4 cm). Spirometric values (FVC, FEV_1, FEV_1/FVC and FEF_{25-75}) were within standard limits throughout the study in both cohorts. Baseline prevalence of BHR was 25% in Santiago and 27% in San Felipe. After six months of follow-up, 13.7% of the exposed cohort and 15.7% of the non-exposed became hyperreactive. During the whole 21 month-period of the study, the rate of new cases of BHR was 16.3% in Santiago and 17.5 in San Felipe. Therefore, these results do not support the hypothesis that a two-year exposure to Santiago's air pollution affects spirometric values or BHR in healthy school children.

Allergy, assessed by Prick test, was higher in Santiago's than in San Felipe's cohort (35 *vs* 24%, respectively; p = 0.032). However, indoor pollution –environmental tobacco smoke and contaminating heating– was higher in San Felipe than in Santiago. The latter could be a possible explanation for the unexpected lack of effect of Santiago's pollution. Another hypothesis for this peculiar finding may be the occurrence of an adaptive mechanism, as it has been reported on dogs exposed chronically to SO_2 (Scanlon, 1987).

EFFECT OF ATMOSPHERIC POLLUTION ON LOWER RESPIRATORY DISEASES IN INFANTS

Since we failed to demonstrate a significant association between air pollution and deterioration of the respiratory system in school children, we moved on to study a more susceptible population. This time the aim was to assess the joint effect of outdoor airborne particles and indoor air pollution sources, particularly environmental tobacco smoke exposure (ETSE) in infants. In addition, we intended to control the effects of climate and socio-economical variables (Oyarzún *et al*, 1998; Pino *et al*, 1998).

We followed 504 infants from 4-months to one-year of age. They were attended in outpatient clinics at Santiago's South-East area on *ad libitum* bases. Diagnoses were

standardized according to World Health Organization criteria. Environmental tobacco smoke exposure (ETSE) was assessed by questionnaire and serum cotinine levels were measured at one year of age. Daily levels of PM_{10} and $PM_{2.5}$, temperature and relative humidity were obtained from the air-monitoring network of Santiago. Fuels for heating and socio-economic status were assessed by a home interview. The outcomes were visits for wheezing bronchitis and pulmonary infections (pneumonitis and bronchopneumonia).

We used two models, both of them controlling for repeated measures (GEE) given that up to 17 visits may have occurred along the follow up: a) logistic regression analysis for estimating the effects of airborne particles in the days previous to each visit, and b) Poisson's regression for estimating the long term effect of particulate matter on accumulated clinic visits for lower respiratory diseases.

In the first model, increases of 50 $\mu g/m^3$ in daily averages of PM_{10} and $PM_{2.5}$ rose the risk of wheezing bronchitis found 4 days later by 11% and 22%, respectively. Worsening of socio-economic status by one SD increased the risk of wheezing bronchitis by 34%. Among climatic variables, only relative humidity was associated with the risk of wheezing bronchitis (Fig 2). In the second model, we did not detect significant effects neither of PM_{10} nor $PM_{2.5}$ on the accumulated visits for wheezing bronchitis along the whole follow-up, being superseded by climatic factors and, principally, by the socio-economic status (Table IV).

With regard to pulmonary infections, we did not find an effect of particulate matter on visits for pneumonitis or bronchopneumonia in the immediate following days. Instead, ETSE (Odds Ratio = 1.41) and a deficient socioeconomic status (OR = 1.41) are the most evident risk factors in determining the occurrence of pulmonary infections in the first model. Also pointing to indoor risks for lung infections, the second model (Poisson's regression) showed that the use of gas for heating was associated to higher risks of lung infection in children (Table IV).

The above results suggest that –in infants– indoor sources of contaminants seem to be associated with lung infections, while outdoor airborne particles –especially $PM_{2.5}$– are likely to be associated with the risk of wheezing bronchitis with a 4-day lag. Over all these factors, a deficient socio-economic status

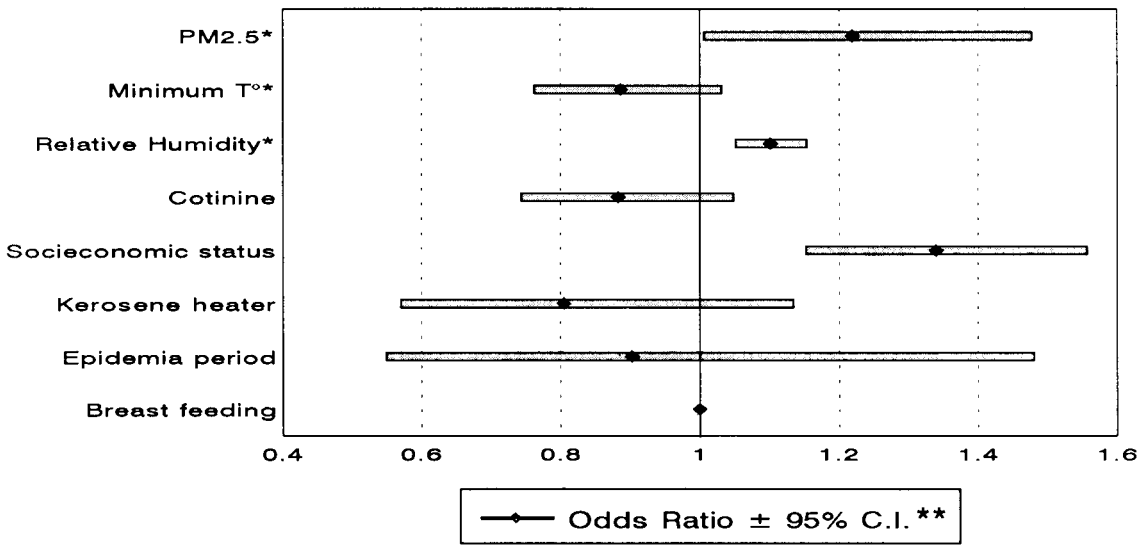

Fig 2. Wheezing bronchitis risk associated with the increase of fine particulate airborne matter: multivariate model. * Best odds ratio estimates of clinic visit for wheezing bronchitis obtained with 4-day lag for increases in $PM_{2.5}$ (50 $\mu g/m^3$), temperature (5°C) and relative humidity (5%). ** Logistic regression, controlling for autocorrelation of non-independent repeated measures (GEE).

Table IV

Risk factors of wheezing bronchitis and lung infection in infants from South-East Santiago

Factors	Wheezing bronchitis RR (CI)	Lung infection * RR (CI)
PM_{10} (100 µg/m^3)	0.92 (0.74-1.14)	1.59 (0.08-3.18)
$PM_{2.5}$ (50 µg/m^3)	0.93 (0.78-1.10)	1.44 (0.84-2.48)
Humidity (5%)	1.10 (1.05-1.15)	1.19 (0.02-1.40)
Minimal temperature (5°C)	0.80 (0.70-0.91)	0.91 (0.57-1.46)
Gas (yes/no)	1.02 (0.63-1.64)	2.49 (0.98-6.30)
Cotinine (ng/ml)	0.87 (0.73-1.02)	1.32 (0.97-1.80)
SES (Graffar score)	1.26 (1.10-1.45)	1.40 (1.00-1.96)

Poisson's regression.
* Lung infection: pneumonitis and bronchopneumonia.
RR (CI) = Relative risk (95% confidence interval)

remains as an important common risk in determining both wheezing bronchitis and lung infections in infants.

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