Coarse Particulate Matter and Hospitalization for Respiratory Infections in Children Younger Than 15 Years in Toronto: A Case-Crossover Analysis

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ABSTRACT. ***Objectives.*** **The purpose of this study was to examine the association between ambient air pollution and hospitalization for respiratory infections among children who were younger than 15 years in Toronto during a 4-year period (1998–2001).**

Methods. **Exposures averaged during periods that varied from 1 to 7 days were used to assess the effects of air pollutants, including thoracic particulate matter (PM_{10}), fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$) particulate matter, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3), on hospitalization for respiratory infections. A case-crossover design was used to calculate odds ratios for the hospitalization adjusted for daily weather conditions with an incremented exposure corresponding to the interquartile range in air pollution exposures.**

Results. **When particulate matter and gaseous pollutants were mutually taken into account, the effect remained pronounced for $PM_{10-2.5}$ in both boys and girls. The adjusted odds ratio for 6-day average exposure to $PM_{10-2.5}$ with an increment of 6.5 $\mu g/m^3$ was 1.15 (95% confidence interval: 1.02–1.30) for boys and 1.18 (95% confidence interval: 1.01–1.36) for girls. The effect also remained for PM_{10} in boys and for NO_2 in girls. $PM_{2.5}$, CO, SO_2, and O_3 showed no significant effects on hospitalization for respiratory infection in both genders when other pollutants were taken into consideration.**

Conclusion. **Our study suggested a detrimental effect of relatively low levels of ambient particulate matter and gaseous pollutants, especially coarse particulate matter and NO_2, on hospitalization for respiratory infections in children. *Pediatrics* 2005;116:e235–e240. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2004-2012; *air pollution, coarse particulate matter, gaseous pollutants, hospitalization for respiratory infection, case-crossover analysis, risk assessment.***

ABBREVIATIONS. CO, carbon monoxide; SO_2, sulfur dioxide; NO_2, nitrogen dioxide; O_3, ozone; PM_{10}, thoracic particulate matter <10 μm in aerodynamic diameter; $PM_{2.5}$, fine particulate matter <2.5 μm in aerodynamic diameter; TEOM, tapered element oscillating microbalance; $PM_{10-2.5}$, coarse particulate matter between 2.5 and 10 μm in aerodynamic diameter; OR, odds ratio; CI, confidence interval; TSP, total suspended particles.

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Lower respiratory infection is a main cause of mortality and morbidity in children in developing countries. Morbidity from childhood respiratory infections is also high in developed countries.[1] Although respiratory infections in children are usually nonfatal in developed countries, they heavily burden the health care systems.[2] Additional progress in preventing the diseases will have a significant impact on children's health.[1]

Although there is abundant evidence linking outdoor air pollution with respiratory symptoms, reduced lung function, bronchial reactivity, and asthma, the relationship of hospital morbidity for respiratory infections to a relatively low level of exposure to air pollution in children has not been well studied and is considered a knowledge gap in developed countries.[3–6] Most previous studies of hospital outcomes associated with air pollution exposures usually either aggregated respiratory infections with other respiratory conditions such as asthma and chronic obstructive pulmonary disease into a single study group or focused on the air pollution effect on respiratory infection in all ages,[7] elderly,[8] or very young children (aged 0–2 years).[9] Children generally breathe more rapidly than adults, they may have more exposure to air pollutants per kilogram of body weight, and respiratory infections are generally more common in boys than in girls.[10] So far it has not been clear whether there are gender differences in effects of ambient air pollutants on respiratory infections in children.[11,12] This study used a case-crossover design to examine the association between ambient air pollution and respiratory infections in boys, girls, and children as a whole who were younger than 15 years in Toronto, Ontario, Canada.

METHODS

The present analysis was based on daily air pollution and hospitalization data collected in metropolitan Toronto between 1998 and 2001. Hospitalization data were obtained from the Discharge Abstract Database. We selected hospitalizations for respiratory infections in the sub-age group (0–14 years) as our study population. Hospitalization for respiratory infections was defined as an admission for which respiratory infections were the primary diagnosis that caused the greatest number of hospital days of stay. Respiratory infections in this analysis included the following conditions: laryngitis, tracheitis, bronchitis, bronchiolitis, pneumonia, and influenza (*International Classification of Diseases, Ninth Revision* codes 464, 466, and 480–487). Admissions were restricted to children who both resided in Toronto and were admitted there. This study included only admissions to hospitals for acute care and active treatment that were considered as emergency or urgent. Both planned admissions and transfers from other institutions were excluded from this analysis. The data were grouped into daily hospital admission counts for both boys and girls.

Air pollution data were obtained from the National Air Pollution Surveillance system, and weather data were obtained from Environment Canada's weather archive. Daily air pollution data were available from a minimum of 4 to a maximum of 7 monitoring stations, including carbon monoxide (CO) and sulfur dioxide (SO_2) from 5 monitoring stations, nitrogen dioxide (NO_2) and ozone (O_3) from 7 stations, and particulate matter of median aerometric diameter <10 and 2.5 μm (PM_{10} and $PM_{2.5}$, respectively) from 4 stations. The study region consisted of the cities of Toronto, North York, East York, Etobicoke, Scarborough, and York. These monitoring sites span the breath of the region and include major population areas. Figure 1 shows the locations of monitoring stations for each air pollutant. CO, NO_2, O_3, and SO_2 were measured using "reference methods" or "equivalent methods" as designated by the US Environmental Protection Agency. CO was measured using nondispersive infrared spectrometry, NO_2 was measured using chemiluminescence, O_3 was measured using chemiluminescence/ultraviolet photometry, and SO_2 was measured using coulometry/ultraviolet fluorescence. $PM_{2.5}$ and PM_{10} were measured using tapered element oscillating microbalance (TEOM) instruments. Although PM_{10} and $PM_{2.5}$ TEOM samplers were not necessarily co-located, we computed the average coarse fraction ($PM_{10-2.5}$) as average PM_{10} minus average $PM_{2.5}$ among sites in Toronto. Although in absolute terms this may introduce error, it should accurately reflect relative day-to-day changes in exposure to coarse particles (Tom Dann, Environment Canada, personal communication, 2004). There is a reasonably good correlation between $PM_{10-2.5}$ from dichotomous monitor and TEOM coarse fraction. The correlation was 0.85 between dichotomous $PM_{10-2.5}$ and the difference between TEOM PM_{10} and TEOM $PM_{2.5}$ at 1 site that had all 3 measures. The correlation was 0.74 when the values were averaged over all sites.

Daily averaging concentrations of each air pollutant were used in this analysis, except daily maximum 1-hour level was used for O_3 because of its diurnal profile of exposures. Average values were calculated when data were available from >1 monitoring station.[13] The concentrations of O_3 are very low at night, peaking in the late afternoon, and then falling off in the evening.[14] Daily information on weather conditions was obtained from Pearson international airport and included daily mean temperatures and dew point temperature.

A bidirectional case-crossover design was used in this study. Bateson and Schwartz[15] reported that the bidirectional case-crossover design can control for different patterns of time trends in exposures and outcomes. The level of air pollution at the time of hospitalization for each case (the case period) was compared with a level obtained in a specified period before and/or after the health event (the control period). Cases in this analysis included only children who were 0 to 14 years of age and were admitted to a hospital in the study area, with respiratory infections as the principal reason for the hospital stay during the period between 1998 and 2001.

The acute effects of environmental exposure may be immediate or may occur several days after exposure. In this study, we examined the acute effect of 1-day to multiple-day averages of air pollution ending on the admission date. Previous studies have documented that increased hospitalizations are most strongly associated with air pollution on the day of admission or within up to 4 days.[4,7,16] A recent study observed that the estimated effect of multiple-day exposures to air pollution could be stabilized on 5 to 6 days.[17] In this study, we calculated 1- to 7-day exposure averages ending on the admission date as the exposures in the case period.

Control periods of 2 weeks before and after the admission date were used in the bidirectional scheme to minimize autocorrelation between case and control exposures and to control for seasonal and long-term effects.[17,18] To be matched with the case period, exposures in the control period were expressed as 1- to 7-day averages for each pollutant ending on the date 2 weeks before and after the admission date.

This study applied conditional logistic regression models for the case-crossover design by using the SAS 8.2 statistical package's PHREG procedure, a program for fitting the Cox proportional hazards model.[19] The conditional likelihood function for logistic regression can be treated as a special case of Cox partial likelihood, which is used to fit the proportional hazards model.[20] We estimated odds ratios (ORs) for hospitalization of respiratory infections in relation to various air pollutants during the case period as compared with the control periods after adjustment for daily

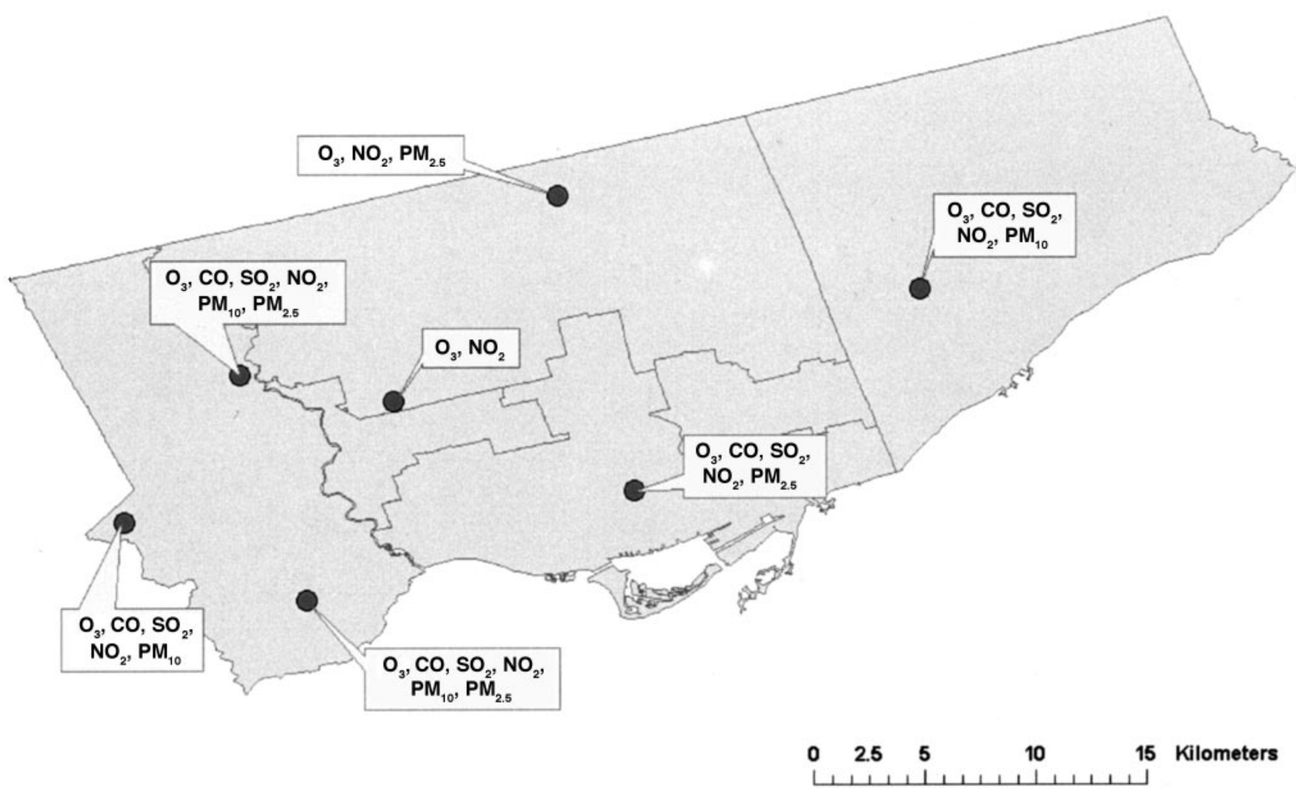

Fig 1. Locations of air-pollution–monitoring stations in Toronto.

mean temperature and dew point temperature. On the basis of previous studies,[16,21] we added squared terms of each of the weather conditions as additional covariates. The ORs were calculated on the basis of an increment in exposure corresponding to the interquartile range of each pollutant. The effects of particulate matter on hospitalization for respiratory infections were examined further, taking into consideration the effects of gaseous pollutants (CO, SO_2, NO_2, and O_3). Particulate matter was also taken into account when the relationships between gaseous pollution and hospitalization for respiratory infections were examined. Because thoracic particulate matter (PM_{10}) is a function of fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$) particulate matter, only fine and coarse particulate matter were considered in the analyses of gaseous pollutants in relation to hospitalization for respiratory infections.

Lumley and Levy[22] first pointed out that a standard conditional logistic regression analysis for bidirectional case-crossover designs is only approximately correct and in some cases estimates would be biased. Some design strategies have been suggested by several studies[18,22,23] to eliminate or reduce these biases. Lumley and Levy[22] have a concern that short-term autocorrelations in the exposures may introduce bias analogous to overmatching in a case-control study. However, such bias will be largely reduced when the interval between case and control periods is weekly based. A 1-week interval allows exclusion of a short-term autocorrelation and ensures independence among observations.[18] A simulation study[23] suggested that selection bias in a case-crossover study design could be reduced by choosing a shorter interval period. A 2-week interval between case and control periods was selected in the present study with considerations of control of short-term autocorrelation and time-varying trends and assessment of potential multiple-day exposure effects. Another simulation study conducted by Levy et al[18] showed that there is little bias (0.4%) when an interval of 2 weeks is used.

RESULTS

Table 1 provides summary statistics for air pollution, weather conditions, and hospitalizations for respiratory infections. There were a total of 6782 hospitalizations for respiratory infections in children who were 0 to 14 years of age (3998 for boys and 2784 for girls) with a daily average of 4.64 (2.74 for boys and 1.91 for girls) in Toronto during the period from 1998 to 2001. Daily information for gaseous pollutants was available for the whole study period. Daily averages of particulate matter were available for ~99% of the total 1461 days between 1998 and 2001.

Correlations between air pollutants are shown in Table 2. $PM_{10-2.5}$ and $PM_{2.5}$ both were highly correlated with PM_{10} ($r = 0.87$ for $PM_{2.5}$, $r = 0.76$ for $PM_{10-2.5}$). A lesser degree of correlation was found between $PM_{10-2.5}$ and $PM_{2.5}$ ($r = 0.33$). Gaseous pollutants all were positively correlated with each other, with the exception of O_3, which was weakly correlated with the other gaseous pollutants. The gaseous pollutants all were positively correlated with ambient particulate matter.

Table 3 provides crude and adjusted ORs and their 95% confidence intervals (CIs) for exposures to each air pollutant in relation to hospitalizations for respiratory infections in boys and girls separately and in children as a whole. Estimates were calculated for 1- to 7-day average levels of each air pollutant. Effects of exposure averaging of 4 and 6 days are presented in Table 3 because most estimated effects of air pollution observed in this study seemed to increase with increasing number of days of exposure and to stabilize at ~4 to 6 days. For particulate matter, $PM_{10-2.5}$ in both boys and girls and PM_{10} only in boys but not in girls showed consistently significant positive associations with hospitalizations for respiratory infections before and after adjustment for gaseous pollutants (Table 3). The adjusted OR for a 6-day average exposure to $PM_{10-2.5}$ with an increment of 6.5 $\mu g/m^3$ was 1.15 (95% CI: 1.02–1.30) for boys and 1.18 (95% CI: 1.01–1.36) for girls. The corresponding OR for PM_{10} with an increment of 12.5 $\mu g/m^3$ was 1.25 (95% CI: 1.01–1.54) in boys. There was no significant association between fine particulate matter ($PM_{2.5}$) and hospitalization for respiratory infections in boys, girls, or children as a whole when gaseous pollutants were taken into account.

For gaseous pollutants associated with hospitalization for respiratory infections, only the effect of 5- to 7-day average exposures to NO_2 in girls but not in boys was significant, and the adjusted OR for a 6-day exposure to NO_2 was 1.31 (95% CI: 1.05–1.63; Table 3). The associations between gaseous pollutants, including CO, SO_2, and NO_2, and hospitalizations of respiratory infections in boys were significant only before adjustment for particulate matter. O_3 showed no significant effect on hospitalizations for respiratory infections in either boys or girls before and after adjustment for particulate matter.

TABLE 1. Distribution of Daily Concentrations of Air Pollutants, Weather Conditions, and Hospitalization for Respiratory Infections Among Children 0 to 14 Years of Age: Toronto, 1998–2001

Variables	Days	Mean	SD	Percentiles				
				Minimum	25th	50th	75th	Maximum
Air pollution								
$PM_{10-2.5}$, $\mu g/m^3$	1442	10.86	5.37	0	7.00	9.67	13.50	45.00
$PM_{2.5}$, $\mu g/m^3$	1461	9.59	7.06	0.25	4.50	7.50	12.33	50.50
PM_{10}, $\mu g/m^3$	1442	20.41	10.14	4.00	13.00	18.00	25.50	73.00
CO, ppm	1461	1.16	0.38	0.38	0.93	1.05	1.37	2.45
SO_2, ppb	1461	4.73	2.58	1.00	3.00	4.00	6.00	19.67
NO_2, ppb	1461	24.54	7.56	9.20	18.75	24.00	29.33	53.75
O_3, ppb	1461	38.06	17.48	3.80	25.83	34.75	47.67	124.50
Weather conditions								
Average temperature, °C	1453	9.44	10.25	−18.40	1.60	10.20	18.40	30.60
Average dew point temperature, °C	1460	3.45	9.45	−26.90	−3.75	3.70	11.40	23.90
Hospitalizations for respiratory infections, *n*								
Total ($n = 6782$)	1461	4.64	3.57	0	2.00	4.00	6.00	22.00
Boys ($n = 3998$)	1461	2.74	2.36	0	1.00	2.00	4.00	14.00
Girls ($n = 2784$)	1461	1.91	1.81	0	1.00	1.00	3.00	11.00

TABLE 2. Correlations Between Daily Concentrations of Air Pollutants: Toronto, 1998–2001

Air Pollutants	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	CO	SO_2	NO_2	O_3
$PM_{2.5}$	1.00	0.33	0.87	0.10	0.47	0.48	0.56
$PM_{10-2.5}$		1.00	0.76	0.06	0.29	0.40	0.30
PM_{10}			1.00	0.10	0.48	0.54	0.54
CO				1.00	0.12	0.20	−0.11
SO_2					1.00	0.61	0.002
NO_2						1.00	0
O_3							1.00

TABLE 3. Crude and Adjusted ORs and 95% CIs for Particulate Matter and Gaseous Pollutants in Relation to Hospitalizations for Respiratory Infections in Boys and Girls Aged 0 to 14 Years in Toronto, 1998–2001, Using Bidirectional Case-Crossover Design

Air Pollutant	Exposure											
	Boys				Girls				Total			
	4 d		6 d		4 d		6 d		4 d		6 d	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Daily average $PM_{10-2.5}$ (6.5 $\mu g/m^3$)												
Crude	1.08	0.99–1.17	1.08	0.99–1.19	1.08	0.99–1.19	1.13*	1.01–1.25	1.09*	1.02–1.16	1.11*	1.03–1.19
Adjusted A	1.14*	1.03–1.27	1.16*	1.03–1.31	1.16*	1.03–1.31	1.24*	1.08–1.42	1.16*	1.07–1.26	1.21*	1.10–1.32
Adjusted B	1.11	1.00–1.24	1.15*	1.02–1.30	1.12	0.99–1.28	1.18*	1.01–1.36	1.13*	1.03–1.23	1.17*	1.06–1.29
Daily average $PM_{2.5}$ (7.8 $\mu g/m^3$)												
Crude	1.06	0.97–1.16	1.01	0.91–1.12	0.97	0.87–1.07	1.00	0.88–1.13	1.02	0.95–1.09	1.00	0.92–1.09
Adjusted A	1.16*	1.03–1.29	1.11	0.97–1.27	1.03	0.90–1.18	1.10	0.94–1.29	1.11*	1.02–1.22	1.11*	1.00–1.24
Adjusted B	1.04	0.87–1.25	0.99	0.80–1.23	0.82	0.66–1.02	0.81	0.62–1.04	0.94	0.81–1.08	0.90	0.76–1.07
Daily average PM_{10} (12.5 $\mu g/m^3$)												
Crude	1.10	1.00–1.21	1.06	0.95–1.19	1.04	0.93–1.16	1.10	0.96–1.26	1.08	1.00–1.16	1.08	0.99–1.19
Adjusted A	1.24*	1.10–1.41	1.21*	1.04–1.40	1.14	0.99–1.33	1.26*	1.06–1.50	1.22*	1.10–1.34	1.25*	1.11–1.40
Adjusted B	1.21*	1.01–1.44	1.25*	1.01–1.54	1.04	0.84–1.28	1.10	0.86–1.42	1.14	0.99–1.32	1.20*	1.01–1.42
Daily average CO (0.4 ppm)												
Crude	1.11	1.01–1.22	1.10	1.00–1.22	0.99	0.89–1.10	1.00	0.89–1.13	1.06	0.98–1.14	1.06	0.98–1.15
Adjusted A	1.13*	1.03–1.24	1.13*	1.02–1.25	1.02	0.92–1.14	1.05	0.93–1.18	1.09	1.01–1.17	1.10*	1.01–1.19
Adjusted B	1.08	0.98–1.20	1.08	0.97–1.20	1.01	0.90–1.13	1.02	0.90–1.15	1.05	0.97–1.14	1.06	0.97–1.15
Daily average SO_2 (3.0 ppb)												
Crude	1.06	0.97–1.16	1.02	0.92–1.13	1.05	0.94–1.16	1.07	0.95–1.21	1.06	0.99–1.13	1.04	0.96–1.13
Adjusted A	1.11*	1.01–1.21	1.08	0.97–1.21	1.07	0.96–1.19	1.12	0.98–1.28	1.10*	1.02–1.18	1.10*	1.01–1.20
Adjusted B	1.02	0.90–1.15	0.99	0.85–1.16	1.09	0.94–1.26	1.07	0.90–1.28	1.05	0.95–1.15	1.03	0.91–1.16
Daily average NO_2 (10.6 ppb)												
Crude	1.09	0.98–1.21	1.07	0.94–1.21	1.06	0.94–1.20	1.17*	1.01–1.36	1.08	1.00–1.18	1.12*	1.01–1.24
Adjusted A	1.14*	1.02–1.28	1.13	0.98–1.29	1.13	0.99–1.30	1.28*	1.09–1.50	1.15*	1.05–1.25	1.20*	1.08–1.34
Adjusted B	0.99	0.84–1.16	1.00	0.83–1.21	1.17	0.97–1.41	1.31*	1.05–1.63	1.06	0.94–1.20	1.13	0.97–1.31
Daily 1-h maximum O_3 (21.8 ppb)												
Crude	1.01	0.89–1.15	0.98	0.84–1.13	0.96	0.83–1.12	0.95	0.80–1.12	0.99	0.89–1.10	0.96	0.86–1.08
Adjusted A	1.13	0.94–1.35	1.11	0.90–1.36	1.14	0.92–1.42	1.13	0.88–1.45	1.14	0.99–1.32	1.13	0.95–1.33
Adjusted B	1.08	0.89–1.31	1.04	0.83–1.30	1.18	0.94–1.47	1.15	0.89–1.50	1.13	0.97–1.31	1.09	0.92–1.30

The ORs were calculated for an interquartile range increment of air pollution, which was calculated on the basis of daily levels; adjusted A ORs were adjusted for daily weather conditions (daily average temperature and dew point temperature); adjusted B ORs for particulate matter were adjusted for daily weather conditions (daily average temperature and dew point temperature) and gaseous pollutants (CO, SO_2, NO_2, and O_3); adjusted B ORs for gaseous pollutants were adjusted for daily weather conditions (daily average temperature and dew point temperature), $PM_{2.5}$, and $PM_{10-2.5}$.
* $P \leq .05$.

DISCUSSION

Air pollution levels are relatively low in Toronto as compared with many other cities of a similar size in the world.[7] Air pollution levels during the study period from 1998 to 2001 generally were lower as compared with those in previous years, between 1980 and 1994.[7] The maximum daily concentration of each pollutant was largely reduced, with a reduction ranging from 12% for O_3 to 65% for SO_2. The mean daily average concentration decreased from 17.99 $\mu g/m^3$ to 9.59 $\mu g/m^3$ for $PM_{2.5}$ and from 30.16 $\mu g/m^3$ to 20.41 $\mu g/m^3$ for PM_{10}. For O_3, however, there was an increase in the mean level of daily maximum 1-hour concentration, and such an increase could be related to warmer summers.[24] The level of PM_{10} and $PM_{2.5}$ never exceeded the US National Ambient Air Quality Standards,[25] with an average level being ~13% of the standard of 150 $\mu g/m^3$ for PM_{10} and 15% of the standard of 65 $\mu g/m^3$ for $PM_{2.5}$. For gaseous pollutants, similarly, the means of daily average levels of CO, SO_2, NO_2, and O_3 were below the National Ambient Air Quality Standards,[25] whereas NO_2 exceeded the standard of 53 ppb on 2 days and O_3 exceeded the standard of 120 ppb on 1 day.

Although air pollution levels are relatively low in Toronto, coarse and thoracic particulate matter in this study showed significant effects on hospitalization for respiratory infection. When gaseous pollutants were included in regression models, the effects of coarse PM remained significant for both genders, and that of thoracic PM was significant for boys. Fine particulate matter was not associated with hospitalization for respiratory infections in either gender.

Previous studies showed inconsistent results regarding particulate matter and respiratory infections. PM_{10} was found to be associated with hospitalizations for pneumonia in all ages in Birmingham, UK, between 1992 and 1994[26] and in elderly people in Minnesota in the period 1986–1989.[27] One study in German cities found that total suspended particles (TSP) was significantly related to pediatrician-reported croup but not to bronchitis.[28] Another study in Rome, Italy, found no relationship between TSP and emergency department admissions for acute respiratory infections in children.[29]

$PM_{10-2.5}$ tended to have a greater effect on hospitalization for respiratory infections than $PM_{2.5}$, which is consistent with previous findings for asthma hospitalizations in children.[7,17] There is also evidence for other health outcomes, including mortality from all causes, respiratory diseases, and cardiovascular disease and hospitalizations for cardiovascular diseases.[30] Coarse particles deposit in the upper airways of the lungs[31] and are associated with increased cytotoxicity and proinflammatory cytokines interleukin-6 and interleukin-8.[32] An experimental study showed that exposure to coarse particles significantly exacerbated pulmonary infection in mice.[33] Particulate matter is likely immunosuppressive and may undermine normal pulmonary antimicrobial defense mechanisms.[34] Additional studies are needed to explore the potential mechanisms.

In our study, some gaseous pollutants showed significant effects on hospitalization for respiratory infections, but the influences were no longer significant when particulate matter was taken into consideration. The only exception is the effect of NO_2 in girls, which remained significant even after controlling for particulate matter. Several previous studies have linked respiratory infection to exposure to NO_2.[28,29,35,36] Two of these studies also looked at the effect of TSP,[28,29] and only 1 study[28] found an association between TSP and croup cases. None of these studies considered the exposure to inhalable particulate matter with aerometric diameter $\leq 10\ \mu m$. Most of these studies did not perform gender-specific analyses. Only 1 case-control study in Stockholm found that wheezing bronchitis was related to outdoor NO_2 exposure in girls but not in boys, which was consistent with our finding of NO_2 effects on respiratory infections. NO_2 exposure was found to be associated with a reduction in peak expiratory flow with virus infection by up to 75%.[5]

Boys have smaller airways relative to their lung volume than girls.[37] Other factors such as smooth muscle and vascular functions and hormonal status may also play a role in the gender-related susceptibility in air pollution effects on respiratory infections. In the present study, boys were more likely to be admitted to the hospital for respiratory infection than girls. A recent study[10] suggested that in children who were younger than 15 years, the hospitalization for respiratory infection was more common in boys than in girls, but such a gender difference decreased with increasing age and reversed in children and young adults. There is a lack of consistent results for gender differences in health effects of various air pollutants.

It remains unclear how ambient outdoor air pollutants interact with respiratory infectious agents. Experimental evidence suggests that exposures to ambient air pollution may adversely affect lung defense functions such as aerodynamic filtration, mucociliary clearance, particle transport, and detoxification by alveolar macrophages. Macrophages can inhibit viral replication and also limit viral infections by removing the debris of destroyed cells and by presenting viral antigens to T lymphocytes.[5]

The present study applied averaged air pollution exposures over centrally sited outdoor monitors to be a surrogate of personal exposures. Misclassification of individual exposures would be a concern when exposure measurement is at the population level. Such an exposure error generally does not lead to substantial bias in the risk estimates while the variance of the estimate is increased.[38] Although the case-crossover study has the advantage of incorporating measurements of exposure or potential effect modifiers into the analysis when this information is available on an individual level, the hospitalization data for the present study were available only at the aggregated level. Future studies applying geospatial modeling would be powerful to estimate environmental exposure concentrations at the neighborhood or even the individual level and therefore take into account variations in environmental exposures across a study region.[39]

CONCLUSIONS

Our study suggested a detrimental effect of relatively low levels of ambient particulate matter and gaseous pollutants on hospitalization for respiratory infections in children. After adjusting for other pollutants, hospitalization for respiratory infections was still significantly associated with coarse particulate matter in both genders, with thoracic particulate matter in boys, and with NO_2 in girls. Effects of fine particulate matter CO, SO_2, and O_3 were not significant when other pollutants were included in the models.

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