Ambient air pollution and children's health: A systematic review of Canadian epidemiological studies

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BACKGROUND: There is growing concern about the health effects of ambient air pollution (AP) in children. The present article summarizes and compares local information regarding the adverse effects of AP on the health of Canadian children with reports from elsewhere.
METHODS: PUBMED, MEDLINE and EMBASE databases were searched for epidemiological studies, published between January 1989 and December 2004, on the adverse health effects of criteria air pollutants among Canadian children.
RESULTS: Eleven studies investigated the association between AP and various respiratory health outcomes, while one study assessed the effect of AP on sudden infant death syndrome. Another study examined the effects of AP on pregnancy outcomes. Most of the available information was from Ontario and British Columbia. Despite inconsistencies among study results and data from elsewhere, evidence from Canadian studies suggest that AP may cause adverse respiratory health effects in children and adverse pregnancy outcomes, and may contribute to infant mortality in Canada.
INTERPRETATION: AP has detrimental health effects among Canadian children. Paediatricians and other health care workers with an interest in child health should encourage parents and children to adhere to smog (AP) advisories. Existing regulatory practices should be reviewed to reduce current levels of ambient air pollutants in Canada.

Key Words: *Air pollution; Biomonitoring; Children; Environmental health; Health effects*

La pollution de l'air atmosphérique et la santé des enfants : Une analyse systématique des études épidémiologiques canadiennes

HISTORIQUE : On s'inquiète de plus en plus des effets de la pollution de l'air atmosphérique (PA) sur la santé des enfants. Le présent article résume l'information locale au sujet des effets néfastes de la PA sur la santé des enfants canadiens et la compare à celle d'ailleurs.
MÉTHODOLOGIE : Dans les bases de données PUBMED, MEDLINE et EMBASE, on a recherché les études épidémiologiques publiées entre janvier 1989 et décembre 2004 au sujet des effets néfastes sur la santé des polluants atmosphériques respectant les critères chez les enfants canadiens.
RÉSULTATS : Onze études portaient sur l'association entre la PA et diverses issues sur la santé respiratoire, tandis qu'une étude traitait de l'effet de la PA sur la mort subite du nourrisson. Une autre étude s'intéressait aux effets de la PA sur les issues de la grossesse. La plus grande partie de l'information disponible provenait de l'Ontario et de la Colombie-Britannique. Malgré des incohérences dans les résultats des études et les données provenant d'ailleurs, les données probantes tirées des études canadiennes indiquent que la PA pourrait être responsable d'effets néfastes sur la santé respiratoire des enfants et sur la grossesse, et elle pourrait contribuer à la mortalité des nourrissons au Canada.
INTERPRÉTATION : La PA a des effets nuisibles sur la santé des enfants canadiens. Les pédiatres et les autres travailleurs de la santé intéressés par la santé des enfants devraient inciter les parents et les enfants à respecter les avis de smog (PA). Il faudrait revoir les pratiques de réglementation en place pour réduire les taux actuels de pollution de l'air atmosphérique au Canada.

Criteria air pollutants (CAPs) are six air pollutants that are regulated by the United States Environmental Protection Agency on the basis of their potential to cause adverse public health and/or environmental effects. These include ozone (O_3), particulate matter (PM) in different fractions (those with mean aerodynamic diameters of 10 µ [PM_{10}], 2.5 µ [$PM_{2.5}$] and between 10 µ and 2.5 µ [$PM_{10-2.5}$]), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and lead (1). Attention is being focused on understanding the adverse health effects (AHEs) of ambient air pollution (AP) in children; they are most susceptible to effects of AP due to the rapid growth and development of their lungs, higher minute ventilation, involvement in vigorous outdoor activities and the greater amount of time spent outdoors compared with adults, as well as their immature immune systems (2,3). A recent policy statement from the American Academy of Pediatrics underscores the increasing global concerns about the health effects of AP in children (4).

Epidemiological studies from around the world report associations between CAPs and morbidity outcomes in children, including asthma exacerbations (5-9), increased prevalence of respiratory symptoms (10,11), decrements in lung function (10,12), deficits in lung function growth

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(13-15), adverse pregnancy outcomes (APOs) (16-19), increased infant mortality (20-22), altered immunity (23), illness-related school absenteeism (24) and birth defects (25).

In Canada, provincial governments and the federal government identify and monitor CAPs (26). Recent studies demonstrate that levels of AP below regulatory limits may still cause AHEs in vulnerable populations, including children (5,11,12,27) and elderly people (28). The present review paper discusses evidence linking AP and AHEs in Canadian children.

METHODS

Data extraction

Studies were identified from PUBMED, MEDLINE and EMBASE databases using the following search terms: ambient air pollution, epidemiological studies, children, Canada and CAPs. Peer-reviewed articles meeting the following criteria were selected: epidemiological studies on health effects of CAPs among Canadian children; studies conducted among all age groups but with clearly specified measures of health outcomes among children; and studies published between January 1, 1989, and December 31, 2004. Relevant articles cited by selected publications were also included. Data on study design and location, confounding factors adjusted for, air pollutants considered, health outcomes measured, and study results were extracted from the selected studies. Studies conducted in Canada among children and adults that did not separately measure the AHEs of AP in children were excluded.

RESULTS

Thirteen studies satisfied the inclusion criteria. The selected studies varied by design, study location, number of CAPs considered, age of study subjects, adjustment for confounding factors and type of health outcomes measured. The majority of studies used time-series analysis to investigate associations between daily variations in AP levels and variations in several health outcomes among children living in geographically defined areas (18,20,27,29-33). Most studies were conducted in the provinces of Ontario (30,31,34) and British Columbia (10,18,27-29). Several studies examined the AHEs of CAPs among children six to 15 years of age (10,27,31,34-36). Some studies assessed the influence of factors such as socioeconomic status (27), sex (27,31,34) and age (28,29,32,33) on the effects of AP on various health outcomes in children. All studies used measurements by ambient air monitoring stations to assess exposure to CAPs. Eleven studies investigated the AHEs of various CAPs on respiratory morbidity outcomes in children (10,27-36). These included increased asthma hospitalization (27,31,34) and asthma emergency department (ED) visits (29,33) (Table 1), increased respiratory hospital admissions (28,30) and ED visits for respiratory illnesses (32) (Table 2), and increased reporting of respiratory symptoms and decrements in lung function (10,35,36) (Table 3). One study (18) assessed the effects of AP on pregnancy outcomes and another study (20) investigated the association between AP and sudden infant death syndrome (SIDS) (Table 4). Data on study design, characteristics of study subjects, air pollutant exposures, AHEs measured, study results and adjustments for confounding factors are summarized in Tables 1 to 4.

DISCUSSION

Adverse respiratory health effects: Increased asthma hospitalization

Although the results from studies investigating the acute effects of AP on asthma hospitalization were not consistent, short-term (day-to-day) increases in ambient air levels of NO_2 and $PM_{10–2.5}$ (31,34) were generally associated with increases in asthma hospitalization for both sexes, while increases in levels of SO_2 and CO were linked to increases in asthma hospital admissions for girls and boys, respectively (27,34). However, Lin et al (27) reported significant associations between NO_2 and SO_2 and asthma hospitalization in children from low-income families in Vancouver, British Columbia, but not for those from high-income families. This is consistent with results from other studies suggesting that children from lower socioeconomic groups may be more susceptible to the AHEs of AP (37,38). Lin et al (34) observed a significant association between ambient levels of CO and asthma hospitalization in boys residing in Toronto, Ontario, although no such association was found among children living in Vancouver (27). Even though ambient levels of $PM_{10–2.5}$ were significantly associated with asthma hospitalization among children in Toronto (31), there was no evidence from any of the reviewed studies to support a link between asthma hospitalization in children and $PM_{2.5}$, PM_{10} and O_3 levels. Nevertheless, a study (39) conducted among asthmatic children in Hong Kong found a significant association between PM_{10} and asthma hospitalization. In addition to differences in study designs, inconsistencies in the results from studies investigating the adverse effects of PM have been attributed to the spatial and temporal variability of the chemical and physical properties of PM, as well as differences in population characteristics and susceptibilities (31).

Increased asthma ED visits

Ambient air levels of O_3 in Saint John, New Brunswick (33), and SO_2 in Vancouver (29) were associated with ED visits for asthma in adults but not in children. Despite the fact that no threshold level has been identified for O_3 above which AHEs are observed (40), studies conducted elsewhere (41) with ambient O_3 concentration exceeding levels recorded by most Canadian studies have documented significant association between ambient O_3 and paediatric asthma ED visits. Ambient air pollutants O_3 and SO_2 were significantly associated with paediatric asthma ED visits in Mexico City, Mexico, where the mean O_3 daily 1 h maximum concentration was 90 ppb (range 10 ppb to 250 ppb) (41), compared with a range of 13.41 ppb to 41.6 ppb for Canadian studies.

TABLE 1
Studies assessing the health effects of criteria air pollutants on asthma hospitalization and emergency department (ED) visits among Canadian children between January 1989 and December 2004

Reference, study location, and data collection period	Study design, subject characteristics and sample size	Exposure to ambient air pollutants	Study findings	Adjustment for confounding factors
Asthma hospitalization				
Lin et al (27), 2004; Vancouver, 1997 to 1998	Time-series analysis; children aged 6–12 years from low- and high-income families; total (n=3822), boys (n=2368), girls (n=1454)	Daily mean concentration (SD): CO 0.96 ppm (0.52) SO_2 4.77 ppb (2.75) NO_2 18.65 ppb (5.59) O_3 28.02 ppb (11.54) Measured the acute effects of 1- to 7-day exposure averages of air pollutants preceding the day of admission	Low-income families Boys: RR corresponding to interquartile range = 1.16 (95% CI 1.06–1.28) for 1-day NO_2 and 1.18 (95% CI 1.03–1.34) for 4-day NO_2 Girls: RR=1.18 (95% CI 1.02–1.36) for a 4-day average and 1.19 (95% CI 1.01–1.40) for SO_2. No observed association between asthma hospitalization and NO_2 or SO_2 in high-income group. No observed association between asthma hospitalization and CO or O_3 in either low- or high-income groups	Daily maximum and minimum temperatures; average relative humidity; day of the week
Lin et al (34), 2003; Toronto, January 1, 1981, to December 31, 1993	Bidirectional case-crossover analyses; children aged 6–12 years; total (n=7319), boys (n=4629), girls (n=2690)	Daily mean concentrations (SD): CO 1.18 ppm (0.05) SO_2 5.36 ppb (5.90) NO_2 25.24 ppb (9.04) O_3 30.39 ppb (17.87) Measured acute effects of 1- to 7-day exposure averages of air pollutants preceding the day of admission	CO Boys: OR corresponding to interquartile increment of CO=1.07 (95% CI 1.01–1.16) for a 2-day exposure average and 1.10 (95% CI 1.02–1.20) for a 4-day exposure average Girls: OR corresponding to interquartile increment in SO_2=1.28 (95% CI 1.08–1.51) for a 7-day exposure average NO_2 Boys: OR=1.09 (95% CI 1.01–1.18) for 2-day exposure average Girls: OR=1.21 (95% CI 1.03–1.42) for a 7-day exposure average. No observed association between O_3 and asthma hospitalization in either boys or girls	Daily maximum and minimum temperatures; average humidity; $PM_{2.5}$ and $PM_{10–2.5}$
Lin et al (31), 2002; Toronto, 1980 to 1994	Bidirectional case-crossover and time-series analyses; children aged 6–12 years; total (n=7319), boys (n=4629), girls (n=2690)	Daily mean concentrations (SD): $PM_{2.5}$ 17.99 (8.49) $PM_{10–2.5}$ 12.17 (7.55) PM_{10} 30.16 (13.61) Measured the acute effects of 1- to 7-day exposure averages preceding the day of admission	Bidirectional case-crossover analysis Boys: RR=1.14 (95% CI 1.02–1.28), girls: RR=1.18 (95% CI 1.02–1.36), for a 8.4 μg/m^3 increase in 6-day averages of $PM_{10–2.5}$ Time-series analysis Boys: RR=1.10 (95% CI 1.03–1.18), girls: RR=1.18 (95% CI 1.08–1.30), for a 8.4 μg/m^3 increase in 6-day averages of $PM_{10–2.5}$. No significant association observed between asthma hospitalization and $PM_{2.5}$ or PM_{10} using both analyses	Daily maximum and minimum temperatures; average relative humidity; day of week; copollutants, including CO, SO_2, NO_2 and O_3
Asthma ED visits				
Stieb et al (33), 1996; Saint John, New Brunswick, 1984 to 1992 (May to September only)	Time-series analysis; children aged <15 years and subjects ≥15 years; 1163 total ED visits in 1987, and 49% were ≤15 years of age. The total number of asthma ED visits during the study period was not documented	Mean of 1 h daily maximum concentration: O_3 41.6 ppb, SO_2 38.1 ppb, NO_2 25.2 ppb Daily mean concentration: SO_4 5.5 μg/m^3; TSPs 5.5 μg/m^3. No data on levels of PM_{10} and $PM_{2.5}$	For both adults and children, asthma ED visits increased by 33% (95% CI 10–56) when daily 1 h maximum O_3 exceeded the 95% percentile concentration (75 ppb) of O_3 two days before admission. Regression models, 1 h maximum and daily mean levels of O_3 were significantly associated with asthma ED for adults but not for children	Maximum dew point temperature; maximum humidex; average relative humidity; copollutants (SO_2, NO_2, TSPs and SO_4) effects

Continued on next page

TABLE 1 – continued
Studies assessing the health effects of criteria air pollutants on asthma hospitalization and emergency department (ED) visits among Canadian children between January 1989 and December 2004

Reference, study location, and data collection period	Study design, subject characteristics and sample size	Exposure to ambient air pollutants	Study findings	Adjustment for confounding factors
Asthma ED visits				
Bates et al (29), 1990; Vancouver, British Columbia, July 1, 1984, to October 31, 1986	Time-series analysis; children aged 0–14 years, adults aged 15–60 years and those aged ≥61 years; total ED visits for asthma between July 1 to June 30, 1985, were n=1357 for those aged 0–14 years, n=1546 for those aged 15–60 years and n=536 for those >60 years of age	Mean of daily 1 h maximum concentrations of SO_2, O_3, SO_4, and COH during summer (May 1 to October 31) and winter (November 1 to April 30) Daily mean concentrations of pollutants were not reported	Adults aged 15–60 years: Same day and previous day levels of SO_2 and SO_4 were significantly (P<0.001) associated with asthma ED visits during summer Children aged 1–14 years: No observed significant association between asthma ED visits for children aged 1–14 years and O_3, SO_2, NO_2, SO_4 or COH	Day of the week

CO Carbon monoxide; COH Coefficient of haze; NO_2 Nitric oxide; O_3 Ozone; PM Particulate matter; SO_2 Sulphur dioxide; SO_4 Sulphite; TSPs Total suspended particulates

Increased respiratory hospital admissions and ED visits

Findings from the present review suggest that short-term variations in the concentrations of O_3 during summer may increase hospital admissions for all respiratory illnesses, including asthma in children. Although same-day concentrations of O_3 were associated with respiratory hospital admissions in Toronto (30), O_3 levels recorded on day 1 and day 4 before admission affected total respiratory admissions (TRAs) maximally in Toronto and Vancouver, respectively (28,30). In addition, previous-day concentrations of CO were associated with TRAs in Vancouver (34). Although the association between TRAs and SO_2 and NO_2 were not statistically significant in Vancouver, both pollutants have been linked to daily TRAs in countries where ambient levels of SO_2 and NO_2 were comparable with (42) or higher (43,44) than those in Canada.

In Montreal, Quebec, previous-day concentrations of ambient air O_3, PM_{10} and $PM_{2.5}$ were associated with ED visits for respiratory diseases for adults but not for children (31). However, ambient levels of $PM_{2.5}$ and PM_{10} (45) in Santiago, Chile, as well as O_3 and PM_{10} levels in Sao Paolo, Brazil (46), have been linked to paediatric respiratory ED visits.

Decrements in lung function and increased reporting of respiratory symptoms

Children from Toronto experienced larger decrements in lung function (forced expiratory volume in 1 s and forced vital capacity), due to high levels of AP, than children from Saskatchewan and Manitoba (35,36). Yu et al (11) reported significantly larger decrements in lung function and a higher prevalence of respiratory symptoms among school children from higher versus lower AP zones in Hong Kong. Contrary to evidence from epidemiological studies indicating that respiratory symptoms may be more prevalent among children from more polluted areas (11,47), two Canadian cross-sectional studies (35,36) did not concur (Table 3). Although short-term changes in levels of PM_{10} were associated with cough, phlegm and sore throat in both asthmatic and nonasthmatic children in Vancouver, decrements in peaked expiratory flow were only observed among asthmatic children (10). Peacock et al (48) reported similar findings among children in Southern England. However, Kim et al (49) found a significant inverse relationship between PM_{10} and lung function in normal children.

APOs

In Vancouver, maternal exposures to SO_2, NO_2 and CO during the first month of pregnancy were associated with intrauterine growth retardation, whereas exposure to SO_2 during the first month of pregnancy was linked to an increased risk of low birth weight (LBW) (18). Additionally, maternal exposure to SO_2 and NO_2 during the last month of pregnancy was associated with an increased risk of preterm birth (18). However, O_3 was not associated with any APOs (18). There is a lack of consistency among studies regarding APOs, both for gestational timing and specific air pollutants. Unlike the Canadian study, two American studies found a link between LBW and maternal exposures to ambient levels of CO exceeding 1.46 ppm (daily average) (50) and 5.5 ppm (three-month average) (51) during the last trimester. The daily mean and maximum concentrations of ambient air CO for the Canadian study were 1.0 ppm and 2.2 ppm, respectively (18). While some studies have supported the Canadian finding linking LBW and maternal exposure to SO_2 during the first trimester (52,53), others have reported associations between LBW and SO_2 levels during the second and last trimesters (54,55). Although PM_{10} and $PM_{2.5}$ have been shown to increase the risks of preterm birth (55,56) and intrauterine growth retardation (57), and $PM_{2.5}$ has been associated with being small for gestational age and LBW (19), the Canadian study did not control for the effects of PM (18).

TABLE 2
Studies assessing the effects of criteria air pollutants on respiratory hospital admissions and emergency department (ED) visits among Canadian children between January 1989 and December 2004

Reference, study location, and data collection period	Study design, subject characteristics and sample size	Exposure to ambient air pollutants	Study findings	Adjustment for confounding factors
Yang et al (28), 2003; Vancouver, British Columbia. Data on hospital admissions for respiratory illnesses* for the period between January 1, 1986, and December 1998	Bidirectional case-crossover analysis; children aged <3 years and adults ≥65 years; total number of respiratory admissions was not documented	Daily mean concentration (SD): O_3 13.41 ppb (6.61); CO 0.98 ppm (0.54); NO_2 18.74 ppb (5.66); SO_2 4.84 ppb (2.84); COH 10^3 (feet), 0.31 (0.17). No data on PM. Examined the effects of same-day and preceding 1- to 5-day levels of air pollutants	Respiratory admissions were associated with O_3 levels 2, 3, 4 and 5 days before admission in both children and the elderly. Strongest association at a lag of 4 days; OR=1.22 (95% CI 1.15–1.30) for children and 1.13 (95% CI 1.09–1.18) for the elderly for an increase in O_3 corresponding to the interquartile range. Order of effects: (O_3>NO_2>CO>COH>SO_2) for children and (O_3>NO_2>COH>SO_2>CO) for the elderly	Copollutants; daily mean maximum and minimum temperatures; average relative humidity; and socioeconomic status
Burnett et al (30), 2001; Toronto, Ontario. Data on daily hospital admissions for acute respiratory illnesses† for the period between January 1, 1980, to December 31, 1994	Time-series analysis; children <2 years old; daily number of respiratory admissions ranged from 0–11 (mean 2.9). No data on total respiratory admissions for the study period	Summer (May to August) mean 1 h maximum concentration: O_3 45.2 ppb, SO_2 11.8 ppb, NO_2 44.1 ppb, CO 1.9 ppb, $PM_{2.5}$ 18.0 μg/m^3, $PM_{10–2.5}$ 16.2 μg/m^3. Levels of pollutants during winter not documented	Percentage increases in daily respiratory admissions were associated with a 45.2 ppb increase in daily 1 h maximum O_3 measured same day = 17.6 (2.04)‡; 2-day lag = 14.2 (3.71); 3-day lag = 8.1 (2.15); 4-day lag = 7.9 (2.10); 5-day lag = 0.8 (0.21); 5-day moving average = 35% (95% CI 19–52). Effects of O_3 persisted after adjustment for copollutants. No observed association between O_3 and hospital admission during winter (September to April)	Daily maximum and minimum temperatures; daily average relative humidity; day of the week; time of the year; and copollutants
Delfino et al (32), 1997; Montreal, Quebec. Data from 25 acute care hospitals on ED visits for respiratory illnesses between June 15 to September 20 in 1992 and 1993. Did not specify types of disease	Time-series analysis; age group considered (daily ED visits): <2 years (n=1440), 2–18 years (n=2444), 19–34 years (n=778), 35–64 years (n=1539), >64 years (n=2367)	Mean concentration (SD): O_3 8 h maximum, 28.8 ppb (11.3); O_3 1 h maximum, 33.2 ppb (12.6); PM_{10} 30.1 μg/m^3 (17.3); $PM_{2.5}$ 18.5 μg/m^3 (14.0); SO_4 51.7 nmol/m^3 (79.1); H^+ (aerosol strong acidity) 11.3 nmol/m^3 (19.9)	Previous-day levels of O_3, PM_{10}, $PM_{2.5}$ and SO_4 were associated with respiratory visits for the elderly (>64 years of age) but not for children	Day of the week, hourly maximum temperature and minimum relative humidity

*International Classification of Diseases, Ninth Revision *(ICD-9) codes 460-519 – all respiratory illnesses; †Asthma (ICD-9 code 493), acute bronchitis/bronchiolitis (ICD-9 code 466), croup (ICD-9 code 464.4) and pneumonia (ICD-9 codes 480-486); ‡Values in parentheses represent the ratio of percentage change to standard error. CO Carbon monoxide; COH Coefficient of haze; NO_2 Nitric oxide; O_3 Ozone; PM Particulate matter; SO_2 Sulphur dioxide; SO_4 Sulphite*

Infant mortality: SIDS

Results from an extensive study (20) conducted in 12 Canadian cities suggest that increases in previous-day and three-day average levels of SO_2 and NO_2 may increase the incidence of SIDS, although ambient levels of CO, PM_{10}, $PM_{2.5}$ and O_3 were not significantly associated with SIDS. While Hoppenbrouwers et al (58) observed a significant association between SIDS and ambient levels of CO measured seven weeks before the last day of life, Klanoff-Cohen et al (59) found a similar association between SIDS and mean monthly levels of CO. In contrast, the Canadian study examined a five-day lag effect of ambient levels of CO on the incidence of SIDS. Evidence from some American studies support the Canadian findings linking SIDS with ambient levels of NO_2 (59) and SO_2 (58,60). However, one study in the Czech Republic found no association between SIDS and ambient levels of SO_2 (61). Despite the fact that the Canadian study did not find any association between ambient levels of PM (PM_{10} and $PM_{2.5}$) and SIDS, other studies have shown that exposure to PM_{10} may increase the rates of postneonatal mortality (21,22,62) and SIDS (21,62,63). An inability to detect an

TABLE 3
Studies assessing the effects of criteria air pollutants on respiratory symptoms and lung function among Canadian children between January 1989 and December 2004

Reference, study location, and data collection period	Study design, subject characteristics and sample size	Exposure to ambient air pollutants	Study findings	Adjustment for confounding factors
Vedel et al (10), 1998; Vancouver Island, British Columbia; diary-reported symptoms and daily peak flow for each subject during the period between May 1, 1990 and March 13, 1992	Longitudinal study; four groups of children aged 6–13 years with physician-diagnosed asthma (n=75), exercise-induced fall in FEV_1 with no asthma diagnosis (n=57), airway obstruction (FEV_1/FVC<0.76) without any of the above (n=18) and control children without any of the above (n=56)	Daily concentration of PM_{10} ranged from 0.2 μg/m^3 to 159 μg/m^3 (median 22.1 μg/m^3, daily mean 27.3 μg/m^3); only 8 days had daily concentrations of PM_{10} >100 μg/m^3	Children with physician-diagnosed asthma: a 10 μg/m^3 increase in 1- to 4-day cumulative lag of PM_{10} above the mean daily PM_{10} concentration of 27.3 μg/m^3 increased the odds of reported cough by 8% (95% CI 0–16) and decrement in PEF by 0.55 L/min (95% CI 0.06–10). Entire sample of children: OR=1.06 (95% CI 1.02–1.10) for cough/phlegm and 1.06 (95% CI 1.01–1.11) for sore throat	Average daily temperature and humidity; daily precipitation; day of the week and month
Stern et al (36), 1994; five communities each in Saskatchewan and southwestern Ontario; data on lung function and respiratory symptoms between October 1985 and March 1986	Cross-sectional study; Caucasian children aged 7–11 years old; total n=4695	Annual mean concentration Ontario: SO_2 2.1 ppb, NO_2 7.3 ppb, O_3 31.4 ppb; Saskatchewan: SO_2 1.2 ppb, NO_2 9.0 ppb, O_3 24.0 ppb	Children from southwestern Ontario had significant (P<0.01) mean decrements of 1.7% in FVC and 1.3% in FEV_1 compared with children from Saskatchewan. No observed significant regional differences for cough, phlegm, persistent wheeze, current asthma and bronchitis	Age, sex, gas cooking at home, parental smoking and education
Stern et al (35), 1989; Tillsonburg, Ontario and Portage la Prairie, Manitoba; data on lung function (FVC and FEV_1) and respiratory symptoms and illnesses using parent-administered questionnaires between September 1983 and April 1984	Cross-sectional study; grade 2–6 children aged 7–12 years; Tillsonburg (n=735), Porte la Prairie (n=895)	Annual averages of SO_2, SO_4 and particulate NO_3 were significantly higher (P<0.05) in Tillsonburg (mean concentrations: SO_2 8.0 ppb, SO_4 3.2 μg/m^3, NO_3 1.5 μg/m^3) than in Portage la Prairie (mean concentrations: SO_2 0.00 ppb, SO_4 0.09 μg/m^3, NO_3 0.7 μg/m^3). No significant differences in levels of NO_2, PM_{10} and O_3 between the two communities	Children from Tillsonburg had significantly (P<0.001) lower levels of 2% for FVC and FEV_1 compared with those in Portage la Prairie. Prevalence of chronic respiratory symptoms was similar in both communities, with the exception of inhalant allergies, which were more frequent among children from Tillsonburg	Parental smoking and education, use of gas or wood heating fuels, pollution levels on day of testing, and differences in age, height or weight

CO Carbon monoxide; FEV_1 Forced expiratory volume in 1 s; FVC Forced vital capacity; NO_2 Nitric oxide; NO_3 Nitrate; O_3 Ozone; PEF Peaked expiratory flow; PM Particulate matter; SO_2 Sulphur dioxide; SO_4 Sulphite

association between ambient levels of PM and SIDS may have resulted from inadequate exposure assessment, given the fact that levels of PM were measured every sixth day (20).

WHY ARE THERE INCONSISTENCIES AMONG STUDY RESULTS?

Measured AP is an indicator of air quality, and the particular mixture in each city varies with sources (64), climate (65), seasons (66) and time of day (67). Most of the studies compared with Canadian studies were conducted in larger and more densely populated cities (eg, Sao Paulo, Mexico City, Santiago and Hong Kong) with relatively higher levels of AP (68,69). The concentrations of O_3 in Canadian cities were relatively low and the AHEs of O_3 and PM among Canadian children were modest compared with children from Latin American countries (29,31,32,39,41). Other factors influencing personal exposure to air pollutants, such as children's time activity patterns, levels of home ventilation (70,71) and indoor levels of air pollutants (72) may differ among cities. A stronger correlation between ambient air levels and personal exposure to PM and gases (O_3, NO_2 and SO_2) has been observed among adults who spend most of their time indoors with their

TABLE 4
Canadian studies assessing the effects of criteria air pollutants on sudden infant death syndrome (SIDS) and pregnancy outcomes from January 1989 to December 2004

Reference, study location and data collection period	Study design, subjects characteristics and sample size	Exposure to ambient air pollutants	Study findings	Adjustment for confounding factors
Infant mortality				
Dales et al (20), 2004; 12 Canadian cities; data on SIDS for the period between January 1, 1984, and December 31, 1999	Time-series analysis; total number of SIDS cases over the study period was 1556	Range of mean 24 h pollutant concentrations (interquartile range): O_3 26.99–36.87 ppb (14.77–28.00 ppb), CO 0.58–1.12 ppm (0.30–0.75 ppm), NO_2 9.56–25.81 ppb (7.50–11.50 ppb), SO_2 0.96–9.93 ppb (1.50–7.83 ppb), PM_{10} 13.51–28.15 μg/m^3 (10.59–22.21 μg/m^3), $PM_{2.5}$ 8.07–16.67 μg/m^3 (6.55–12.14 μg/m^3), $PM_{10-2.5}$ 5.46–15.88 μg/m^3 (4.59–14.47 μg/m^3)	NO_2 and SO_2 increases (interquartile range) were significantly (P=0.0311) associated with an 11.6% increase in incidence of SIDS and 6.05% for increases in 3-day average levels. Effects of CO were not persistent after adjustment for confounders. There was no observed association between SIDS and O_3 or PM	Daily mean temperature and humidity, maximum change in barometric pressure and seasonality
Pregnancy outcomes				
Liu et al (18), 2003; Vancouver; British Columbia; data on live births for the period between January 1 and December 31, 1998	Time-series analysis; singleton live births (n=229,085), average LBW (4.0%), preterm birth (5.3%), and IUGR rates (9.4%)	Daily mean (SD) of maximum concentration: SO_2 4.9 ppb (13.4), NO_2 19.4 ppb (34.1), CO 1.0 ppm (2.2), O_3 13.4 ppb (27.9)	LBW: OR=1.11 (95% CI 1.01–1.22, for a 5.0 ppb increase) for exposure to SO_2 during the first month of pregnancy Preterm birth: OR=1.09 (95% CI 1.01–1.14) for a 5.0 ppb increase in SO_2 and OR=1.08 (95% CI 1.01–1.15) for a 1.0 ppm increase in CO during the last month of pregnancy IUGR: OR=1.07 (95% CI 1.01–1.13) for a 5.0 ppb increase in SO_2, OR=1.05 (95% CI 1.01–1.10) for a 10.0 ppb increase in NO_2 and OR=1.06 (95% CI 1.01–1.10) for a 1.0 ppm increase in CO during the first month of pregnancy. No observed association was observed between O_3 and any adverse pregnancy outcome	Maternal age, parity, infant sex, gestational age, birth weight and month of birth

CO Carbon monoxide; IUGR Intrauterine growth retardation; LBW Low birth weight; NO_2 Nitric oxide; O_3 Ozone; PM Particulate matter; SO_2 Sulphur dioxide

windows frequently opened than among those who often close their windows (70). The relatively longer duration of winter in Canada, as well as the longer period of time spent within insulated homes by Canadian children during winter, may possibly reduce personal exposure to ambient air pollutants during this period (73). In Hong Kong, where residents spend approximately 86% of their time indoors, indoor levels of NO_2, PM_{10}, $PM_{2.5}$ and CO significantly contribute to personal exposures for all age groups (74,75). Latin American cities have higher indoor and outdoor AP levels, have less developed health care services and are of a relatively lower income level than Canada (76-79). Children from lower socioeconomic backgrounds and/or communities with reduced access to medical care are known to be more susceptible to the AHEs of AP (37,38).

CONCLUSIONS

AP is a global issue with serious public health implications. Despite inconsistencies among study results and data from elsewhere, evidence from Canadian studies suggest that AP may cause adverse respiratory health effects in children, APOs and contribute to infant mortality in Canada. Most of the available information is from Ontario and British Columbia. Inconsistencies among Canadian studies and other studies may be attributed to differences in study designs, climates, exposures, population characteristics, genetic susceptibilities, and temporal and spatial variations in specific pollutant levels and chemical composition. However, findings from Canadian studies, as well as evidence from elsewhere, generally suggest that AP may cause AHEs in children. Existing regulatory practices must be reviewed to reduce current levels of air pollutants in Canada. Paediatricians and other health workers with interests in child health should encourage children and parents to observe smog (AP) advisories.

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