Air Pollution and Emergency Department Visits for Asthma in Windsor, Canada

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ABSTRACT

Objectives: The city of Windsor is recognized to have poor air quality in comparison with other Canadian cities. However, relatively few studies have evaluated associations between day-to-day fluctuations in air pollution levels and respiratory health in Windsor. In this study, we examined associations between short-term changes in ambient air pollution and emergency department (ED) visits for asthma in Windsor.

Methods: A time-stratified case-crossover design was applied to 3,728 ED visits for asthma that occurred in Windsor area hospitals between 2002 and 2009. Daily air pollution levels for the region were estimated using Environment Canada's network of fixed-site monitors. ED visits were identified through the National Ambulatory Care Reporting System (NACRS). Odds ratios and their corresponding 95% confidence intervals were estimated using conditional logistic regression, and were adjusted for the confounding influence of daily number of influenza ED visits and weather variables using natural spline functions.

Results: Statistically significant associations were observed between ambient air pollution levels and ED visits for asthma in Windsor. Effects were particularly pronounced among children 2 to 14 years of age between April and September. Namely, increases in the interquartile range with 1-day lagged exposure to SO2, NO2 and CO levels were associated with increased risks of an asthma visit of 19%, 25% and 36%, respectively.

Conclusion: Exposure in Windsor to ambient air pollution increases the risk of ED visits for asthma, particularly among children.

Key words: Air pollution; asthma; child; risk; cross-over studies

La traduction du résumé se trouve à la fin de l'article.

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Ambient air pollution is recognized to adversely affect respiratory health. Several studies conducted in Canada[1-3] and elsewhere[4-7] have found that day-to-day increases in pollution levels are associated with the exacerbation of asthma. While these findings suggest that children and the elderly are more susceptible to the effects of ambient pollution,[3] the pathogenesis remains poorly understood, and there is no consensus on which constituents of air pollution are most harmful.

To date, most studies of ambient air quality and hospitalization have relied on hospital admissions rather than emergency department (ED) presentations. The risk estimates in these studies are based on only those individuals whose condition is severe enough to warrant being admitted to the hospital subsequent to presentation at the ED. As a result, their findings are not easily generalizeable to all asthmatic events. As highlighted by Pereira and colleagues,[6] 60% of patients who present to an emergency department with asthma have "mild" symptoms, and of these, only 13% are subsequently admitted. For this reason, emergency department presentation data are better suited to characterize the overall impact that air pollution has on asthma exacerbation severe enough for persons to urgently seek health care.

The city of Windsor is recognized to have poorer air quality relative to other cities in Canada.[8] Higher pollution levels in Windsor are caused, in part, by upwind sources that include coal-powered electricity generating stations and other industrial sources located in Michigan and the Ohio Valley. Air quality in this city is also significantly affected by the Windsor-Detroit gateway, which is the busiest international trade corridor in North America. In 2003, an estimated 16 million-plus cars and trucks crossed this gateway.[9]

Despite the recognition that Windsor has perhaps the poorest air quality among Canadian cities, only two studies[10,11] have evaluated associations between day-to-day fluctuations in air pollution levels and adverse health effects. These reports found that daily levels of ambient air pollution were associated with hospital admissions for respiratory diseases[11] and for cardiovascular diseases[10] in Windsor. At this time, we know of no study that has investigated the association between day-to-day fluctuations in ambient pollution levels in Windsor and ED visits for asthma.

With this background, we present our findings from a time-stratified case-crossover study that investigates associations between short-term fluctuations in ambient air pollution concentrations and presentation to emergency departments in Windsor area hospitals for the treatment of asthma.

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METHODS

Emergency department (ED) visits for asthma in Windsor were captured through the National Ambulatory Care Reporting System (NACRS), a reporting system for ED visits in Canada.[12] Asthma cases in Windsor were identified in the NACRS based on the first three digits of available postal codes corresponding to the city of Windsor. The NACRS database is estimated to capture more than 97% of the emergency department visits in Ontario.[13] The International Classification of Diseases 10th (ICD-10) revision coding was used to identify discharge diagnoses of asthma (ICD-10: J45, J46, T486, Y556, Z825).

Available patient data allowed us to identify ED visits for asthma for the period between April 1, 2002 and March 31, 2009. We also tabulated the daily number of visits for influenza (ICD-10: J09, J10, J11) in order to adjust in multivariable regression models for the potential confounding influence of viral respiratory seasonal epidemics. We excluded asthma visits among children less than two years of age as the diagnosis of asthma in this age group is often confused with bronchiolitis.[14] Additional information contained in the NACRS database and used in this study included the date of visit, the age and sex of the patient and a unique patient identification number to allow tracking of multiple visits for asthma.

Estimates of daily average ambient concentrations of air pollution were obtained from the National Air Pollution Surveillance Network maintained by Environment Canada which collects air pollution levels through automated fixed-site monitoring stations.[15] Daily mean concentrations were calculated for the following pollutants: nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter of median aerometric diameter less than 2.5 microns ($PM_{2.5}$). For ozone (O_3), the daily maximum value was used due to its large diurnal variations. One-day lagged exposure to air pollutants was used as our metric to examine the temporal relationship between outdoor air pollution and ED visits for asthma. This was done because respiratory health effects are mostly seen when air pollution levels are lagged for one day[4-6,11,16] and because there is a short delay from the onset of an increase in air pollution levels to the appearance of adverse health outcomes and the seeking of medical care.[17] Daily mean temperature and relative humidity were obtained and used to adjust the risk estimates. These meteorological variables were modeled as natural spline functions with 4 degrees of freedom.

All statistical analyses were conducted with SAS, version 9.2[18] using the procedure PHREG to perform the conditional logistic regression. This study used a case-crossover design, which is an adaptation of the case-control study in which cases serve as their own control.[19] For each ED visit, an individual's exposure at the "index" time was compared to the exposure at a referent time interval. Referent intervals were close in time to the case event in order to control for seasonal patterns of disease occurrence. In our study, the matching of control to case periods – which latter refers to the day that the ED visit for asthma occurred – was done using a time-stratified approach. Specifically, referents were selected from the same day of the week during the same month and year as the case interval to control the influence of "day of week" effects on the frequency of ED visits.[20] The case event day was not eligible to be selected as a control interval. Matched sets consisted of one case period and either three or four referent periods, depending on the day of the month when the case period occurred and the number of days in the month.

Table 1. Number of Emergency Department Visits for Asthma, by Age Group, Sex, Season and Year in Windsor Between April 1, 2002 and March 31, 2009

Characteristic	Number of Visits	%
Age (in years)		
2-14	1235	33.1
15-39	1502	40.3
40-59	714	19.2
≥60	277	7.4
Sex		
Male	1690	45.3
Female	2038	54.7
Season		
Spring/Summer (April to September)	1812	48.6
Fall/Winter (October to March)	1916	51.4
Year		
2002	781	21.0
2003	326	8.7
2004	525	14.1
2005	384	10.3
2006	419	11.2
2007	422	11.3
2008	692	18.6
2009*	179	4.8
Total visits	3728	100

* Until March 31, 2009.

Odds ratios (OR) were estimated along with their accompanying 95% confidence intervals. The odds ratio was calculated in relation to an increase in the interquartile range (IQR) based on the daily mean levels of each air pollutant over the entirety of the study period. The use of the IQR made it easier to compare risk estimates across different pollutants that were measured on different scales. Stratified analyses were conducted to examine whether associations between air pollution and asthma were similar across age groups and seasons (April to September, October to March). This was done because people are recognized to spend a greater proportion of their time outdoors during spring/summer season.[21] Additionally, from the perspective of statistical power, there was a nearly equal number of ED visits in both periods.

RESULTS

A total of 3,728 ED asthma visits occurred during the study period (Table 1). Approximately 33% of these visits occurred in children 2-14 years of age, 7.4% among those ≥60 years of age. There were more visits among females (54.6%) than males and slightly more visits during fall/winter season (51.4%). Table 2 presents a summary of each pollutant's levels in this study; ozone, as an example, is shown to be particularly high in summer as compared with winter.

Adjusted odds ratios for ED visits for asthma based on a 1-day lagged exposure to air pollution stratified by age group and season are displayed in Table 3. Statistically significant associations were observed between 1-day lagged exposure to SO_2, NO_2, CO, O_3 and ED visits for asthma in certain subgroups. The strongest associations were observed during the spring/summer season among children 2 to 14 years of age. In this age group, an increase in the interquartile range with 1-day lagged exposure to SO_2, NO_2 and CO was associated with a respective 19%, 25% and 36% increase in the odds of an asthma ED visit. A statistically significant association was also observed for 1-day lagged exposure to CO and asthma visits among children throughout the year (OR 1.15, 95% CI 1.02-1.31). Among adults aged 40 to 59 years of age, a 60% increase in the odds ratio of an asthma ED visit was observed for a 1-day lagged exposure to O_3 for the period between October and March. Ozone

Table 2. Summary of Air Pollution Data in Windsor Between April 1, 2002 and March 31, 2009 on the Days When There Are Cases and Controls

Pollutant	IQR	Season			
		October to March		April to September	
		Mean	Range	Mean	Range
SO_2 (µg/m³)	4.5	5.8	0-30.5	4.7	0-24.0
NO_2 (µg/m³)	9.0	19.9	4.0-55.5	14.9	3-43.5
CO (ppm)	0.2	0.4	0-2.4	0.3	0-0.9
O_3, Max (µg/m³)	26.0	27.9	1.5-85.5	55.0	13.0-128.5
$PM_{2.5}$ (µg/m³)	3.3	7.1	1.0-31.6	7.4	1.0-30.5

IQR = Interquartile range.

Table 3. Adjusted Odds Ratio* for the Relationship Between a 1-day Lag Exposure to Outdoor Air Pollution and Emergency Department Visits for Asthma in Windsor Stratified by Age Group and Season

Pollutant	Age Group (years)	All Seasons		Season			
				October to March		April to September	
		OR	95% CI	OR	95% CI	OR	95% CI
SO_2	All ages	1.02	(0.97, 1.06)	0.97	(0.92, 1.03)	**1.10†**	**(1.02, 1.18)**
	2-14	1.04	(0.96, 1.12)	0.96	(0.87, 1.06)	**1.19**	**(1.04, 1.36)**
	15-39	0.99	(0.92, 1.06)	0.97	(0.89, 1.06)	1.01	(0.90, 1.13)
	40-59	1.00	(0.90, 1.11)	0.92	(0.81, 1.05)	1.13	(0.96, 1.33)
	≥60	1.12	(0.96, 1.31)	1.14	(0.94, 1.39)	1.19	(0.90, 1.57)
NO_2	All ages	0.99	(0.93, 1.05)	0.95	(0.88, 1.02)	1.09	(0.98, 1.21)
	2-14	1.05	(0.95, 1.16)	0.97	(0.85, 1.10)	**1.25**	**(1.04, 1.50)**
	15-39	0.98	(0.89, 1.07)	0.98	(0.88, 1.10)	0.97	(0.81, 1.14)
	40-59	0.94	(0.82, 1.06)	0.84	(0.72, 1.02)	1.16	(0.93, 1.45)
	≥60	0.95	(0.77, 1.17)	1.02	(0.80, 1.31)	0.86	(0.56, 1.32)
CO	All ages	1.00	(0.93, 1.07)	0.95	(0.87, 1.04)	1.08	(0.97, 1.21)
	2-14	**1.15**	**(1.02, 1.31)**	1.04	(0.88, 1.23)	**1.36**	**(1.12, 1.64)**
	15-39	0.92	(0.83, 1.03)	0.91	(0.79, 1.03)	0.96	(0.80, 1.14)
	40-59	0.97	(0.83, 1.13)	0.94	(0.77, 1.14)	1.03	(0.79, 1.33)
	≥60	0.89	(0.69, 1.14)	0.94	(0.69, 1.29)	0.86	(0.55, 1.35)
O_3 (Max)	All ages	**1.11**	**(1.01, 1.21)**	1.19	(0.99, 1.44)	1.08	(0.97, 1.21)
	2-14	1.01	(0.86, 1.19)	0.92	(0.66, 1.27)	1.05	(0.87, 1.27)
	15-39	1.12	(0.97, 1.30)	1.29	(0.95, 1.76)	1.09	(0.92, 1.28)
	40-59	1.19	(0.97, 1.47)	**1.60**	**(1.04, 2.45)**	1.07	(0.83, 1.36)
	≥60	1.17	(0.83, 1.66)	1.23	(0.59, 2.54)	1.17	(0.78, 1.74)
$PM_{2.5}$	All ages	1.00	(0.97, 1.04)	0.99	(0.93, 1.04)	1.03	(0.97, 1.08)
	2-14	0.97	(0.90, 1.04)	0.95	(0.86, 1.06)	0.99	(0.90, 1.09)
	15-39	1.02	(0.97, 1.09)	0.99	(0.91, 1.08)	1.05	(0.97, 1.14)
	40-59	1.01	(0.93, 1.09)	1.02	(0.92, 1.13)	1.00	(0.88, 1.13)
	≥60	1.01	(0.88, 1.17)	0.94	(0.76, 1.17)	1.11	(0.90, 1.36)

* Odds ratios were calculated in relation to an increase in the interquartile range (IQR) of selected air pollutants and were adjusted for relative humidity, temperature and daily number of visits for influenza (all ages combined).
† Statistically significant results are in **bold font**.

was also associated with asthma ED visits for all ages when looking at all seasons (OR 1.11, 95% CI 1.01-1.21). Other windows of exposure were considered (lagged 0-2 day and 3-5 day averages), but only a statistically significant association was observed for the same-day exposure to CO and ED visits for asthma (OR 1.32, 95% CI 1.02-1.69). No associations were observed for $PM_{2.5}$ and asthma ED visits.

DISCUSSION

In this study, we have found positive associations between ambient levels of SO_2, NO_2, CO, O_3 and ED visits for asthma. This suggests that a reduction in these pollutant levels could decrease morbidity and the associated direct health care costs of asthma, especially among children, in the city of Windsor.[22]

Most of the strongest positive associations were seen among children 2 to 14 years of age during spring/summer season and specifically for SO_2, an industrial air pollutant, and NO_2 and CO, whose levels are heavily influenced by traffic-related sources. Possible biologic mechanisms that can explain these findings include that children spend more time outside than adults, that their peripheral airways are more susceptible to inflammatory narrowing than adults[23] and that they retain a disproportionately higher amount of air pollution per unit body weight than adults.[24] Furthermore, it has been shown that NO_2 makes people more susceptible to respiratory viral infections that exacerbate asthma.[25] Increased levels of NO_2 were also associated with increase in bronchitis symptoms[26] and deficit of lung function in children who spend more time outside.[27] Regarding CO, in previous findings, this pollutant has been associated with COPD[16,28] and upper respiratory infection ED visits.[28] In addition, in our study, CO was also found to be associated with ED visits for asthma among adults, 40 to 59 years of age, for the period between April and September. In this same age group, but for the winter season, O_3 was associated with a 60% increase in ED visits for asthma. Similar patterns of risk were observed in a previous study for ozone and asthma exacerbation.[3] The findings of this study are similar to the ones found in previous reports of air pollution and adverse health effects in Canadian cities[2,3,10] and elsewhere in the world.[6,29] One possible difference with the Edmonton report is that associations were strongest for 3- and 5-day averages among young children (2-4 years of age) while we observed that effects were more pronounced among children (2-14 years of age) with 1-day lagged exposure. Additionally, range levels of pollutants in our study were similar with levels found in previous reports in Australia[6] and Southern California.[26]

There are some methodological limitations in this study. The case-crossover approach relies on the assumption that the event of inter-

est – here, ED visits for asthma – defines the case intervals while no such visit can occur during the matched control intervals. This assumption can be violated under the scenario of recurrent events. This would occur, for example, if an individual visited an emergency department for asthma on a day that was deemed to be a control interval. However, in our study, the exclusion of these matched sets – 0.9% of all ED visits for asthma – did not change the odds ratios in any appreciable way. Another limitation could be related to the exposure pattern to air pollution for each individual in this study. This would be due to the fact that regional measures of air pollution from fixed-site monitoring stations were taken as the measure of exposure to air pollutants rather than taking each person's level of exposure. Assuming that these measurement errors are non-differential between case and control intervals, this would usually result in an underestimation of the odds ratios which would bias the results towards the null.[30] Furthermore, we did not adjust for the confounding influence of outdoor levels of aeroallergens, but we believe, based on previous findings,[3] that this would not lead to an appreciable change in risk. This study could also lack statistical power to clearly evaluate some of the non-statistically-significant associations reported, especially among the elderly and for $PM_{2.5}$.

Strengths of our study include that the odds ratios reported have been adjusted for the possible confounding influence of several other factors that vary on a day-to-day basis. Moreover, the case-crossover design of our study is effective for controlling for potential confounding factors at the individual level such as age, sex, cigarette smoking and prior respiratory conditions. The time-stratified case-crossover approach has also been demonstrated as a suitable method to control for time trends in both air pollution exposures and outcomes.[20] Finally, this study relied on reliable data for assessment of exposure to air pollution and the identification of ED visits for asthma, which has been shown to be an effective way of identifying asthma diagnoses.[2-4,28]

The results of this study showed that traffic-related air pollution and industrial-related pollution increase the risk of ED visits for asthma in the city of Windsor in Ontario, particularly among children. The results of this study and previous reports in Windsor[10,11] suggest that there are tangible health benefits that could be achieved through the reduction of ambient air pollution levels.

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RÉSUMÉ

Objectifs : La ville de Windsor est reconnue pour avoir une qualité d'air inférieure comparativement à d'autres villes canadiennes. Toutefois, peu d'études ont évalué l'association entre des fluctuations quotidiennes dans les niveaux de polluants atmosphériques et des problèmes respiratoires à Windsor. Le but de cette étude est d'évaluer l'association entre le changement à court terme de polluants atmosphériques et les admissions à l'urgence dans la ville de Windsor.

Méthodes : Un devis d'étude cas-témoins de croisement stratifié sur le temps a été appliqué à 3 728 visites dans les départements d'urgence des

hôpitaux de la ville de Windsor entre 2002 et 2009. Les niveaux de polluants atmosphériques pour cette région ont été estimés en utilisant les sites de surveillance de la pollution atmosphérique d'Environnement Canada. Les visites à l'urgence ont été identifiées avec le Système national d'information sur les soins ambulatoires (SNISA). Des rapports de cote (RC) accompagnés d'intervalle de confiance à 95 % ont été générés en utilisant la régression logistique conditionnelle et ont été ajustés pour les facteurs confondants d'admissions quotidiennes à l'urgence pour un diagnostique d'influenza et des variables climatiques en utilisant des fonctions splines naturelles.

Résultats : Des associations statistiquement significatives ont été observés entre les polluants atmosphériques et les admissions à l'urgence pour de l'asthme à Windsor. Les effets étaient particulièrement prononcés chez les enfants de 2 à 14 ans entre les mois d'avril et septembre. Spécifiquement, une augmentation dans l'écart interquartile avec un décalage d'une journée dans l'exposition au SO_2, NO_2 et CO augmentait le risque d'une visite à l'urgence pour de l'asthme de 19 %, 25 % et 36 %, respectivement.

Conclusion : L'exposition à la pollution de l'air ambiante à Windsor augmente le risque d'admission à l'urgence pour de l'asthme, particulièrement chez les enfants.

Mots clés : pollution de l'air; asthme; enfant; risque; cas-témoins de croisement