ehp ENVIRONMENTAL HEALTH PERSPECTIVES

ehponline.org

The Air Quality Health Index and Asthma Morbidity: A Population-Based Study

Teresa To, Shixin Shen, Eshetu G. Atenafu, Jun Guan, Susan McLimont, Brian Stocks, Christopher Licskai

http://dx.doi.org/10.1289/ehp.1104816

Online 10 October 2012

NIEHS
National Institute of Environmental Health Sciences

National Institutes of Health
U.S. Department of Health and Human Services

The Air Quality Health Index and Asthma Morbidity: A Population-Based Study

Teresa To[1,2,3], Shixin Shen[1,2], Eshetu G. Atenafu[2,4], Jun Guan[3], Susan McLimont[1], Brian Stocks[5], Christopher Licskai[6,7]

Institutional Affiliations
[1]Child Health Evaluative Sciences, The Hospital for Sick Children, Toronto, Ontario
[2]Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario
[3]Institute for Clinical Evaluative Sciences, Toronto, Ontario
[4]University Health Network, Toronto, Ontario
[5]Ontario Lung Association, Toronto, Ontario
[6]Department of Medicine, University of Western Ontario, London, Ontario
[7]St. Joseph's Health Care, London, Ontario

Work attributed to: Child Health Evaluative Sciences, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario.

Corresponding Author
Dr. Teresa To
Child Health Evaluative Sciences
The Hospital for Sick Children
555 University Avenue
Toronto, Ontario M5G 1X8
Phone: 416-813-8498; Fax: 416-813-5979; Email: teresa.to@sickkids.ca

Running title: Impact of air quality on asthma morbidity

Key words: air pollution, air quality health index, asthma, health services utilization

Acknowledgements
The authors are thankful to the Ministry of the Environment and the Institute for Clinical Evaluative Sciences for provision of the provincial data for this study.

Funding
This study was funded by the Ontario Lung Association, through a grant from the Government of Ontario. Dr. Teresa To is supported by the University of Toronto, Life Sciences Committee, Dales Award in Medical Research. The opinions, results and conclusions reported in this article are those of the authors and do not necessarily represent those of the Ontario Lung Association, Government of Ontario, or the Ministry of the Environment. The authors declare they have no actual or potential competing financial interests.

List of Abbreviations

AQHI	Air Quality Health Index
AQI	Air Quality Index
CI	Confidence intervals
CO	Carbon Monoxide
Day-0	Zero days lagged from peaked exposure
Day-1	Peaked exposure was measured 1 day prior to health care visits
Day-2	Peaked exposure was measured 2 days prior to health care visits
ED	Emergency department
ICAP	Illness Cost of Air Pollution Study
LHIN	Local Health Integration Networks
NO_2	Nitrogen dioxide
OASIS	Ontario Asthma Surveillance Information System
O_3	Ground-level ozone
$PM_{2.5}$	Fine particulate matter with a diameter of 2.5 micrometers or less
RR	Rate ratio
SO_2	Sulphur dioxide
TRS	Total reduced sulphur compounds

ABSTRACT

BACKGROUND: Exposure to air pollution has been linked to the exacerbation of respiratory diseases. The Air Quality Health Index (AQHI), developed in Canada, is a new health risk scale for reporting air quality and advising risk reduction actions.

OBJECTIVE: We used the AQHI to estimate the impact of air quality on asthma morbidity adjusting for potential confounders.

METHODS: Daily air pollutant measures were obtained from 14 regional monitoring stations in Ontario. Daily counts of asthma-attributed hospitalizations, emergency department (ED) visits, and outpatient visits were obtained from a provincial registry of 1.5 million individuals with asthma. Poisson regression was used to estimate health services rate ratios (RR) as a measure of association between the AQHI or individual pollutants and health services use. We adjusted for age, sex, season, year, and region of residence.

RESULTS: The AQHI was significantly associated with increased use of asthma health services on the same day and on the two following days, depending on the specific outcome assessed. A unit increase in the AQHI was associated with a 5.6% increase in asthma outpatient visits (RR=1.056; 95% CI: 1.053, 1.058) and a 2.1% increase in the rate of hospitalization (RR=1.021; 95% CI: 1.014, 1.028) on the same day, and with a 1.3% increase in the rate of ED visits (RR=1.013; 95% CI: 1.010, 1.017) after a 2-day lag.

CONCLUSIONS: The AQHI was significantly associated with the use of asthma-related health services. Timely AQHI health risk advisories with integrated risk reduction messages may reduce morbidity associated with air pollution in individuals with asthma.

Introduction

Asthma is a common chronic respiratory disease with a worldwide prevalence ranging from 5-18% (Bousquet et al. 2007; Farrar 2005; Masoli et al. 2004), marked by inflammation, bronchial hyper-responsiveness, and airflow limitation. Acute asthma attacks that result in health services use are common (Carlton et al. 2005; Chapman et al. 2001; FitzGerald et al. 2006; Lai et al. 2003; Rabe et al. 2004; Sekerel et al. 2006), and have been associated with a variety of air pollutants (Gilliland 2009; Lin et al. 2005; Stieb et al. 2002; Stieb et al. 2009; Weinmayr et al. 2010). Six pollutants are considered in the reporting of air quality in North America using the Air Quality Index (AQI): ground-level ozone (O_3), fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and total reduced sulphur (TRS) compounds. Since 1988, AQI values in Ontario are established by the Ministry of the Environment to reflect air quality management objectives to protect human health. AQI is based on the six pollutants noted above, the AQI is reported as the value for the single pollutant with the highest AQI (Air Quality Index (AQI) 2012; Balluz et al. 2007; Shenfeld and Yap 1989). Health Canada and Environment Canada began a collaboration in 2001 to develop a new index named the Air Quality Health Index (AQHI) which was derived based on the combined impact of three pollutants (NO_2, O_3 and $PM_{2.5}$) (Air Quality Health Index 2012a). AQHI values are linked to specific risk-reduction health messages designed to educate individuals on the impact of air quality on health, and to advise specific risk reduction actions (Table 1) (Air Quality Health Index, b; Environics Research Group Ltd 2005).

The AQHI has been shown to predict all-cause mortality data in Canada (Stieb et al. 2008), but the AQHI has not been evaluated as a predictor of morbidity, which may be particularly important for conditions such as asthma where mortality is low. In this study, we examined associations between daily values of the AQHI and health services use for asthma, as an indication of the relationship between air quality and asthma morbidity, in the province of Ontario, Canada, from 2003 to 2006.

Methods

Data Source

Our study was based in Ontario, Canada's largest province, which has a multicultural population of more than 12 million residents that includes more than one-third of Canada's total population. The provincial health system is organized into 14 Local Health Integration Networks (LHIN). Ontario has a universal, single-payer health-care system that covers all physician and hospital services, and the personal health information collected for the administration of this system is available in 3 large databases. The Ontario Health Insurance Plan Database contains information (including a diagnosis) on all fee-for-service billings for physician services rendered in Ontario since July 1, 1991. The Canadian Institute for Health Information Database records the primary diagnosis and secondary diagnoses for all patients discharged from acute-care hospitals. The Ontario Registered Persons Database includes information on gender, birth date and residence postal code. We linked these databases together on an individual level using an encrypted version of the unique Ontario health insurance number given to all Ontario residents. Such linkage allows for protection of the identities of individuals while examining their health services use across health administrative databases.

Study Population

The Ontario Asthma Surveillance Information System (OASIS) Database is a validated registry of all Ontario residents with asthma that was generated by using the Ontario Health Insurance Plan and Canadian Institute for Health Information health administrative databases described above. To compile the OASIS database, individuals with asthma were identified using a previously validated asthma case definition, as described in detail elsewhere and used in previous studies (Gershon et al. 2009; To et al. 2004b; T. To et al. 2006; To et al. 2010). This case definition, which requires at least 2 asthma physician visits within 2 consecutive years, or at least 1 asthma hospitalization ever, yielded 89% sensitivity and 72% specificity in children (aged 0–17 years) and 84% sensitivity and 76% specificity in adults (aged 18 years or over) compared with physician diagnosis documented in medical charts (Gershon et al. 2009; To et al. 2004b; To et al. 2006; To et al. 2010). Patients remain in the database as part of the asthma population until they move out of the province or die, consistent with previous evidence indicating that asthma, once diagnosed, may remit but does not resolve (Stern et al. 2008; van Den Toorn et al. 2000). The present study included data from all individuals in the OASIS database who had asthma from January 1, 2003 to December 31, 2006 (To et al. 2004a; T To et al. 2006).

The OASIS database is housed at the Institute for Clinical Evaluative Sciences in Toronto, Canada. This study was approved by Research Ethics Boards at The Hospital for Sick Children Research Institute and the Institute for Clinical Evaluative Sciences, Toronto, Canada.

Air Quality Measures

Hourly AQHI calculations and air pollutant measures (NO_2, O_3 and $PM_{2.5}$) from January 1, 2003 to December 31, 2006 were obtained from the Ontario Ministry of the Environment for 22 monitoring stations across the 14 Ontario LHINs. Air pollutants were measured hourly, 24 hours per day. For LHINs with more than one monitoring station, a mean daily maximum AQHI was calculated using the maximum daily AQHI measured by the monitors within the LHIN, i.e. a LHIN-specific daily maximum of AQHI. All individuals living within a LHIN were assigned the same exposure. The same method of exposure assignment was used to determine exposures to the individual pollutants on which the AQHI is based. For descriptive purposes the LHINs were grouped into North, South, Central, East and West regions.

Asthma-Related Outcomes

Daily counts of asthma incidence, prevalence, asthma-attributed hospital admissions, ED visits, and outpatient physician claims were identified from OASIS using International Classification of Diseases 10th Revision codes (J45, J46). Each day, new asthma cases not previous identified were included as incidence and were then added to the existing asthma cases (prevalence) from that day on forward. Count data were arranged by the 14 LHINs of residence and 5 age groups (0-4, 5-9, 10-19, 20-59 and 60+). Asthma incidence and prevalence rates were calculated per 1000 Ontario residents, while rates of hospitalizations, ED visits and outpatient visits were per 1000 residents with asthma (i.e., individuals included in the OASIS database).

Statistical Analysis

For descriptive analysis, we calculated annual mean daily maximum values of air quality measures and annual rates of asthma incidence, prevalence and health services use for each year and for the study period as a whole (2003 through 2006). Poisson regression was used to estimate associations between daily AQHI values or individual pollutant measures and daily health service use, including exposures on the same day (Day-0) and lagged 1 and 2 days (Day-1 and Day-2, respectively). All regression models included offset terms for asthma prevalence and included indicator terms to adjust for age (5 groups), season, LHIN, and year. Rate ratios (RR) from the Poisson regression models were used to estimate associations between asthma-attributed health service and a 1-unit increase in the AQHI or an incremental increase in individual air pollutants (10-ppb for NO_2 and O_3, 10-$\mu g/m^3$ for $PM_{2.5}$) (Frome 1983). All tests were performed at a 5% significance level. Associations with the individual pollutant components of the AQHI (NO_2, O_3 and $PM_{2.5}$) were estimated using Poisson regression models that included all 3 pollutants. In addition, all models were stratified by age group and by season. Finally, we derived predicted average daily rates of asthma health services use for each level of AQHI with all model covariates at their mean values. Analyses were performed using SAS version 9.2 (SAS Institute Inc., Cary, NC).

Results

Air Quality Measures

The overall mean daily maximum AQHI was 3.66 ±1.29, indicating low to moderate health risk (Table 2). The highest mean daily maximum AQHI was 3.87 in 2003 and the lowest was 3.34 in 2006, The mean daily maximum AQHI showed yearly fluctuations. Of the five regions, the Central Ontario, which includes Toronto, had the highest mean daily maximum AQHI (3.94 ±1.34 average over all years of the study) while the North region had the lowest (3.30 ±1.19) (Table 2). Daily maximum AQHI was highest in the summer (4.07 ±1.43) and lowest in the fall (3.18 ±1.19).

Health Services Use

The mean annual asthma incidence and prevalence rates per 1000 Ontario residents during 2003–2006 were 6.9 and 126.7, respectively (Table 2). The annual incidence of asthma fluctuated between a low of 6.7 in 2006 and a high of 7.1 per 1000 Ontario residents in 2003. The overall prevalence of asthma increased by 7.0% from 2003 to 2006 (Table 2). The annual mean rates of asthma outpatient visits, ED visits and hospitalizations over the entire study period per 1000 residents with asthma were 572.0, 38.8 and 5.0 respectively. All asthma health services outcomes were higher in 2003 than in 2006, though outpatient visits were the only outcome that decreased monotonically over time.

The Central Ontario region had the highest annual mean rate of outpatient visits per 1000 residents with asthma (622.8) while the North region had the highest mean rate of ED visits (56.2) (Table 2). Annual rates for use of all 3 asthma health services were highest among 0-4 year olds and lowest among those aged 10-19 years, and were highest in the fall and lowest in the summer.

Adjusted Asthma Health Services Rate Ratios (RR)

Daily maximum AQHI was associated with a positive and significant increase in the use of each asthma health service evaluated during at least one lag period (Table 3). The adjusted asthma outpatient visit rate ratio was highest for AQHI on the same day (Day-0 RR=1.056; 95% CI: 1.053, 1.058) indicating that a unit increase in the AQHI was associated with an estimated 5.6% increase in asthma outpatient visits. However, there was a significant negative association between asthma outpatient visits and the AQHI two days before the visit (Day-2 RR= 0.983; 95% CI: 0.981, 0.986). The asthma hospitalization rate ratio also was highest for AQHI on the same day and the previous day (both Day-0 and Day-1 RR=1.021; 95% CI: 1.014, 1.028), suggesting 2.1% increase in hospital admissions attributed to asthma for each unit increase in the AQHI. The RR for asthma ED visits was highest for AQHI two days before the visit (Day-2 RR=1.013; 95% CI: 1.010, 1.017) suggesting a 1.3% increase in asthma ED visits per unit increase in AQHI.

Results from the multipollutant Poisson regression model adjusted for covariates were also shown in Table 3. The highest NO_2-specific RR was found on Day-0 for asthma outpatient visits (RR=1.117; 95% CI: 1.114, 1.120) suggesting a nearly 12% increase in outpatient claims per 10 unit increase in NO_2. The highest O_3-specific RR was found on Day-2 for hospitalizations (RR=1.043; 95% CI: 1.036, 1.051). The highest $PM_{2.5}$-specific RR was observed on Day-0 for ED visits (RR=1.028; 95% CI: 1.022, 1.035).

Figure 1 showed the results of the Poisson regression models stratified by age groups. The youngest (0-4 years) and the oldest age groups (60 years or above) had the highest RRs for asthma ED visits on Day-2 and hospitalization on Day-1. The oldest age group had the highest RR for asthma outpatient claims on Day-0. Figure 2 showed results stratified by seasons. Although the RRs showed no difference in asthma ED visits or hospitalization by seasons, RR for Day-0 were higher in the spring and summer for asthma outpatient claims.

NO_2 was associated with higher asthma outpatient visits and hospitalizations particularly in the summer, O_3 had the highest association with outpatient claims in the spring and summer, while $PM_{2.5}$ had the highest associations with ED visits and outpatient claims in the winter (see Supplemental Material, Table S1). In general, higher associations were observed in the younger age groups.

Predicted Average Daily Rate of Asthma Health Services Use

Predicted average daily rates of asthma health services use per unit increase in AQHI at Day-0 in total and by age groups were calculated from the adjusted Poisson regression models. The increase in predicted daily rates of asthma health services use per unit increase in AQHI was highest in the very young and the oldest population. Predicted daily rates and the expected counts of asthma health services use by AQHI values as applied to an asthma prevalent population with average values of model covariates. There were about 1.5 million individuals living with asthma in Ontario during the study period, based on the provincial population of 12 million and asthma prevalence of 12.6%. The predicted daily rates per 1000 residents with asthma on days when the AQHI = 3 (indicating low health risk) were 1.49 for outpatient asthma claims, 0.106 for asthma ED visits, and 0.013 for asthma hospitalizations, which we estimate would result in nearly 2278 outpatient visits, 160 ED visits and 20 hospital admissions attributed to asthma (Table 4). If the AQHI was 10 (high health risk), these daily expected counts would increase to 3330, 164 and 24, respectively, representing increases of 46%, 2% and 16% relative to counts on days when AQHI = 3, respectively. As these are daily expected counts calculated from daily rates, the absolute increase in health care burden could be large if more days in a year have higher AQHI measures.

Discussion

This study extends our understanding of the deleterious health effects of air pollutants by associating asthma morbidity directly with a simple population based air quality health risk scale. Our results suggest that an increase in the daily maximum AQHI is associated with an increase in asthma health services use. Associations are evident on the day of exposure for exposure 1 and 2 days before the outcome. The AQHI as well as individual pollutants demonstrated the associations with health services use.

Our findings are supported by previous studies of individual pollutants and the multi-variable AQHI scale (Table 5). According to a study of 12 Canadian cities that included data for nearly two decades, each unit increase in the AQHI was associated with a 1.2% increase in mortality (Stieb et al. 2008). A comprehensive, systematic synthesis of 109 daily time-series studies suggested that acute exposures to air pollutants such as NO_2, O_3, and PM_{10} contribute to all-cause mortality, with NO_2 and PM_{10} showing stronger associations with respiratory mortality (Stieb et al. 2002). Furthermore, a study of 11 Canadian cities from 1980 to 1991 found significant associations between NO_2 and O_3 and non-accidental mortality (Burnett et al. 1998).

While AQHI has been associated with mortality, its association with morbidity outcomes has not been fully assessed. A number of recent studies have reported associations between individual air pollutants and adverse health outcomes. According to a systematic review of 36 studies, PM_{10} and potentially NO_2 were significantly associated with the occurrence of asthma symptom episodes among individuals under 18 years of age (Weinmayr et al. 2010). A time-series analysis based on nearly 400,000 ED visits at 14 hospitals in seven Canadian cities during the 1990s and early 2000s concluded that daily average concentrations of O_3 exhibited the most consistent associations with ED visits for respiratory conditions, and that PM_{10} and $PM_{2.5}$ were strongly associated with visits for asthma during warm season (Stieb et al. 2009). Furthermore, a four-year study found associations between hospitalization for respiratory infections in children younger than 15 years in Toronto and relatively low levels of ambient particulate matter and gaseous pollutants, especially coarse particulate matter and NO_2 (Lin et al. 2005).

While our study is not a formal validation study of AQHI morbidity outcomes, it is the first study to use a large body of population-based data to evaluate associations between AQHI and asthma-related morbidity. We used asthma as an index disease because it is very common and is the fastest-growing chronic disease in North America, and because air pollutants have been associated with asthma symptoms and exacerbations. Recent studies have suggested that other chronic diseases may also be aggravated by air pollution, including chronic obstructive pulmonary disease (COPD), heart disease (including heart attack and stroke) and diabetes (Andersen et al. 2012; Hoffmann et al. 2012; Ko and Hui 2012; Lavigne et al. 2012; Wellenius et al. 2012). Our study supports the utility of AQHI as an exposure metric for studies of the impact of ambient air pollution on health outcomes, and our approach may serve as a prototype for studies of the impact of air quality on other chronic diseases.

The use of large health administrative and environmental databases helped ensure the comprehensiveness, representativeness, and generalizability of our findings while minimizing selection bias, but there are some limitations. We used a large population-based database from Canada, potentially limiting the generalizability of our findings to other populations. The AQHI, a recent Canadian innovation, is an index of air quality that is focused on health risk and on the communication of that risk to the general public. However, at this time the AQHI is not used outside of Canada. Although our estimates were adjusted for several confounding factors, we could not account for other potential confounders such as smoking, housing conditions, indoor air quality, and ethnicity. Since all individuals residing within a region were assigned the same level of exposure without formally accounting for variations within a region, there is potential in misclassifying exposure. In addition, health administrative data may underestimate morbidities associated with asthma and misdiagnosis was possible. However, we attempted to reduce the misclassification of outcomes by using a validated and highly specific case definition of asthma.

The multivariable analyses in our study were conducted using fixed effect Poisson regression models that adjusted for confounders including region and year. Since our study used data from 2003 to 2006 obtained for various regions in Ontario, there may be some degree of spatial autocorrelation as well as time dependency in the data that we have not fully accounted for. Methods used by others that take into account spatial autocorrelation include complex regression approaches such as Poisson regressions with distance-based agglomeration-specific spatial random effects and Poisson regressions with neighbourhood-based agglomeration-specific spatial random effects (Mohebbi et al. 2011). According to simulation results reported by Mohebbi et al, ignoring spatial autocorrelation may potentially overstate the degrees of freedom in the data and consequently underestimate standard errors (Mohebbi et al. 2011). While this error would not affect rate ratio estimates, it is likely that we have overstated their statistical significance. While it would be desirable to account for residual spatial correlation in analyses, it is challenging to specify the correct correlation structure and apply appropriate spatial smoothing. However, a more sophisticated temporal and spatial analysis could be considered in future to account for potential autocorrelation and time dependency of the data.

The AQHI is designed to help individuals make decisions to protect their health by limiting short-term exposure to air pollution and adjusting their activity when air pollution levels are high. In our study, rate ratios were estimated assuming constant linear associations per unit increase of AQHI. Future studies should examine specific AQHI cut-points in relation to the levels of severity of health risks.

The National Illness Cost of Air Pollution (ICAP) study conducted by the Canadian Medical Association in 2008 suggested that respiratory illness associated with exposure to air pollution accounted for a significant burden to the health care system and productivity loss (The Canadian Medical Association 2008). Our study suggests a statistically significant increase in asthma health services use per unit increase in AQHI. The AQHI health messages providing recommendations on how to adjust outdoor activity levels in accordance with AQHI levels may play an important role in informing individuals about health risks and air pollution and may contribute to reducing unnecessary health care use due to adverse health outcomes attributable to exposure to air pollution.

Conclusion

Our study was the first to use population data to study associations between asthma morbidity and the AQHI. Daily rates of asthma health services use predicted based on our estimates may be useful for health care resource allocation and planning, and may guide the timing of asthma education and management interventions and air quality risk reduction campaigns.

Our findings support the use of the AQHI as a chronic disease morbidity index. As an air quality health risk advisory tool, the composite AQHI may reflect the combined effects of ambient air pollutant exposures relevant to patients with asthma. Furthermore, the AQHI was developed as communication tool that includes simple risk-reduction advice, permitting practical implementation as an asthma trigger avoidance management strategy. The AQHI may be useful for forecasting asthma morbidity associated with outdoor air pollution and education about the AQHI may help reduce health services use by individuals living with asthma.

References

Air Quality Health Index. 2012. Air Quality Health Index. Available: http://www.ec.gc.ca/cas-aqhi/default.asp?lang=En&n=CB0ADB16-1 [accessed Mar 11 2011].

Air Quality Health Index. 2012. AQHI categories and messages. Available: http://www.ec.gc.ca/cas-aqhi/default.asp?lang=En&n=79A8041B-1 [accessed Mar 11 2011].

Air Quality Index (AQI). 2012. Air Quality Index (AQI). Available: http://www.airqualityontario.com/reports/summary.php [accessed December 22 2011].

Andersen ZJ, Raaschou-Nielsen O, Ketzel M, Jensen SS, Hvidberg M, Loft S, et al. 2012. Diabetes incidence and long-term exposure to air pollution: a cohort study. Diabetes Care 35(1):92-98.

Balluz L, Wen XJ, Town M, Shire JD, Qualter J, Mokdad A. 2007. Ischemic heart disease and ambient air pollution of particulate matter 2.5 in 51 counties in the US. Public Health Rep 122(8):626.

Bousquet J, Clark T, Hurd S, Khaltaev N, Lenfant C, O'byrne P, et al. 2007. GINA guidelines on asthma and beyond. Allergy 62(2):102-112.

Burnett RT, Cakmak S, Brook JR. 1998. The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities. Can J Public Health 89(3):152-156.

Carlton BG, Lucas DO, Ellis EF, Conboy-Ellis K, Shoheiber O, Stempel DA. 2005. The status of asthma control and asthma prescribing practices in the United States: results of a large prospective asthma control survey of primary care practices. J Asthma 42(7):529-535.

Chapman KR, Ernst P, Grenville A, Dewland P, Zimmerman S. 2001. Control of asthma in Canada: failure to achieve guideline targets. Can Respir J 8 Suppl A:35A-40A.

Environics Research Group Ltd. 2005. Development of a Health-based Air Quality Index for Canada - Public Opinion Research 2004-05 H1011-040011/001CY. Ottawa (ON): Health Canada.

Farrar JR. 2005. The global burden of asthma and current approaches to its management.

FitzGerald JM, Boulet LP, McIvor RA, Zimmerman S, Chapman KR. 2006. Asthma control in Canada remains suboptimal: the Reality of Asthma Control (TRAC) study. Can Respir J 13(5):253-259.

Frome EL. 1983. The analysis of rates using Poisson regression methods. Biometrics 39:665-674.

Gershon AS, Wang C, Guan J, Vasilevska-Ristovska J, Cicutto L, To T. 2009. Identifying patients with physician diagnosed asthma in health administrative databases. Can Respir J 16(6):183-188.

Gilliland FD. 2009. Outdoor air pollution, genetic susceptibility, and asthma management: opportunities for intervention to reduce the burden of asthma. Pediatrics 123(Suppl 3):S168-173.

Hoffmann B, Luttmann-Gibson H, Cohen A, Zanobetti A, de Souza C, Foley CS, H.H., et al. 2012. Opposing effects of particle pollution, ozone, and ambient temperature on arterial blood pressure. Environ Health Perspect 120(2):241-246.

Ko FW, Hui DS. 2012. Air Pollution and COPD. Respirology 17(3):395-401.

Lai CK, De Guia TS, Kim YY, Kuo SH, Mukhopadhyay A, Soriano JB, et al. 2003. Asthma control in the Asia-Pacific region: the Asthma Insights and Reality in Asia-Pacific Study. J Allergy Clin Immunol 111(2):263-268.

Lavigne E, Villeneuve PJ, Cakmak S. 2012. Air pollution and emergency department visits for asthma in Windsor, Canada. Can J Public Health 103(1):4-8.

Lin M, Stieb DM, Chen Y. 2005. Coarse particulate matter and hospitalization for respiratory infections in children younger than 15 years in Toronto: a case-crossover analysis. Pediatrics 116(2):e235-240.

Masoli M, Fabian D, Holt S, Beasley R. 2004. The global burden of asthma: executive summary of the GINA Dissemination Committee Report. Allergy 59:469-478.

Mohebbi M, Wolfe R, Jolley D. 2011. A Poisson regression approach for modelling spatial autocorrelation between geographically referenced observations. BMC Med Res Methodol 11:133-.

Rabe KF, Adachi M, Lai CK, Soriano JB, Vermeire PA, Weiss KB, et al. 2004. Worldwide severity and control of asthma in children and adults: the global asthma insight and reality surveys. J Allergy Clin Immunol 114(1):40-47.

Sekerel BE, Gemicioglu B, Soriano JB. 2006. Asthma insights and reality in Turkey (AIRET) study. Respir Med 100(10):1850-1854.

Shenfeld L, Yap D. 1989. Ontario's New Air Quality Index - design and operating experience. . Toronto: Ontario Ministry of the Environment.

Stern DA, Morgan WJ, Halonen M, Wright AL, Martinez FD. 2008. Wheezing and bronchial hyper-responsiveness in early childhood as predictors of newly diagnosed asthma in early adulthood: a longitudinal birth-cohort study. Lancet 372(9643):1058-1064.

Stieb DM, Burnett RT, Smith-Doiron M, Brion O, Hyun Shin H, Economou V. 2008. A new multipollutant, no-threshold air quality health index based on short-term associations observed in daily time-series analyses. J Air Waste Manag Assoc 58:435-450.

Stieb DM, Judek S, Burnett RT. 2002. Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season. J Air Waste Manag Assoc 52:470-484.

Stieb DM, Szyszkowicz M, Rowe BH, Leech JA. 2009. Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. Environ Health 8:25.

The Canadian Medical Association. 2008. National illness costs of air pollution. Ottawa: The Canadian Medical Association.

To T, Dell S, Dick P, Cicutto L, Harris J, Tassoudji M, et al. 2004a. Burden of childhood asthma: ICES investigative report. Internet. Toronto.

To T, Dell S, Dick P, Cicutto L, MacLusky I, Tassoudji M, et al. 2004b. Defining asthma in children for surveillance. . Am J Respir Crit Care Med 169(7):A383.

To T, Dell S, Dick PT, Cicutto L, Harris JK, MacLusky IB, et al. 2006. Case verification of children with asthma in Ontario. Pediatr Allergy Immunol 17(1):69-76.

To T, Gershon A, Tassoudji M, Guan J, Wang C, Estrabillo E, et al. 2006. The burden of asthma in Ontario: ICES investigative report. Internet. Toronto.

To T, Wang C, Guan J, McLimont S, Gershon AS. 2010. What is the lifetime risk of physician diagnosed asthma in Ontario, Canada? Am J Respir Crit Care Med 181(4):337-343.

van Den Toorn LM, Prins JB, Overbeek SE, Hoogsteden HC, de Jongste JC. 2000. Adolescents in clinical remission of atopic asthma have elevated exhaled nitric oxide levels and bronchial hyperresponsiveness. Am J Respir Crit Care Med 162(3 Pt 1):953-957.

Weinmayr G, Romeo E, De Sario M, Weiland SK, Forastiere F. 2010. Short-term effects of PM10 and NO2 on respiratory health among children with asthma or asthma-like symptoms: a systematic review and meta-analysis. Environ Health Perspect 118(4):449-457.

Wellenius GA, Burger MR, Coull BA, Schwartz J, Suh HH, Koutrakis P, et al. 2012. Ambient air pollution and the risk of acute ischemic stroke. Arch Intern Med 172(3):229-234.

Table 1. Risk levels and health messages according to levels of the Air Quality Health Index (AQHI)

Health Risk	Air Quality Health Index	Health Messages	
		At Risk Population[a]	General Population
Low	1-3	Enjoy your usual outdoor activities.	Ideal air quality for outdoor activities.
Moderate	4-6	Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms.	No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	7-10	Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High	Above 10	Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

[a]People with heart or breathing problems are at greater risk.

Table 2. Mean measures of Air Quality Health Index (AQHI) and asthma outcomes by year, age, season, and region

Covariates	Air Quality Measure Mean ± Standard Deviation	Annual Asthma Incidence and Prevalence Rate per 1000 Population		Annual Asthma Health Services Use Rate per 1000 Residents with Asthma[d]		
	AQHI	Incidence[b]	Prevalence[c]	Outpatient visits	ED visits	Hospital admissions
Year						
2003	3.87 ± 1.37	7.11	122.60	622.90	41.71	5.41
2004	3.64 ± 1.18	6.84	124.80	577.20	38.95	5.11
2005	3.83 ± 1.40	7.03	128.20	563.80	39.10	5.38
2006	3.34 ± 1.12	6.65	131.20	524.00	35.22	4.14
2003 to 2006	3.66 ± 1.29	6.91	126.70	572.00	38.75	5.01
Age Groups						
0-4	Not Applicable[a]	41.72	114.86	1759.06	174.96	42.08
5-9		13.54	217.56	622.64	44.34	6.63
10-19		5.67	224.10	315.00	23.37	1.67
20-59		3.90	100.42	526.68	34.56	2.74
60+		4.88	110.17	693.54	27.28	3.84
Season						
Spring (Mar-May)	3.95 ± 1.17	7.20	126.08	591.08	40.42	5.20
Summer (Jun-Aug)	4.07 ± 1.43	5.47	126.88	486.52	29.71	3.30
Fall (Sep-Nov)	3.18 ± 1.19	7.59	127.38	628.57	45.92	6.67
Winter (Dec-Feb)	3.45 ± 1.14	7.38	126.51	581.20	38.80	4.85
Region						
North	3.30 ± 1.17	5.81	121.69	534.71	56.16	6.92
South	3.74 ± 1.43	5.70	113.82	514.78	37.43	6.10
Central	3.94 ± 1.19	7.91	130.10	622.76	29.70	4.59
East	3.47 ± 1.14	7.21	137.80	561.24	43.75	4.13
West	3.77 ± 1.14	5.74	114.45	529.24	45.73	5.77

Note: AQHI = Air Quality Health Index; ED = emergency department.

Data stratified by age groups, season and region are based on data averaged from 2003-2006.

[a]AQHI is non applicable by age groups.

[b]Asthma incidence is the number of new cases identified each day that are not known prior to that day.

[c]Asthma prevalence is the sum of current and new cases.

[d]This population includes all Ontario residents in the OASIS database.

Table 3. Rate ratios (RR) for asthma health outcomes in association with a 1-unit increase in the AQHI (Air Quality Health Index)

	Asthma Outpatient Visits		Asthma ED Visits		Asthma Hospital Admissions	
Lags[a]	RR[b]	95% CI	RR	95% CI	RR	95% CI
Day-0						
AQHI	1.056	(1.053 , 1.058)	1.003	(0.999 , 1.007)	1.021	(1.014 , 1.028)
NO_2	1.117	(1.114 , 1.120)	0.976	(0.971 , 0.980)	1.025	(1.017 , 1.034)
O_3	0.979	(0.976 , 0.981)	1.008	(1.004 , 1.012)	1.017	(1.009 , 1.024)
$PM_{2.5}$	0.982	(0.978 , 0.985)	1.028	(1.022 , 1.035)	0.997	(0.986 , 1.007)
Day-1						
AQHI	1.019	(1.016 , 1.021)	1.005	(1.001 , 1.009)	1.021	(1.014 , 1.028)
NO_2	1.022	(1.020 , 1.025)	0.976	(0.972 , 0.981)	1.011	(1.003 , 1.018)
O_3	1.018	(1.015 , 1.020)	1.014	(1.009 , 1.018)	1.031	(1.023 , 1.039)
$PM_{2.5}$	0.990	(0.986 , 0.993)	1.022	(1.016 , 1.028)	1.002	(0.991 , 1.012)
Day-2						
AQHI	0.983	(0.981 , 0.986)	1.013	(1.010 , 1.017)	1.008	(1.001 , 1.015)
NO_2	0.959	(0.956 , 0.962)	0.994	(0.990 , 0.999)	0.991	(0.983 , 0.999)
O_3	1.016	(1.014 , 1.019)	1.010	(1.006 , 1.014)	1.043	(1.036 , 1.051)
$PM_{2.5}$	1.006	(1.002 , 1.009)	1.017	(1.011 , 1.023)	0.992	(0.981 , 1.002)

[a] The lag variable measures number of day from when the peak AQHI was measured, i.e. Day-0 indicates zero lag (same day), Day-1 indicates peak AQHI was measured 1 day prior to the health care visit and similarly Day-2 indicates peak AQHI was measured 2 days prior.

[b] All health services use rate ratios (RR) per unit increase in AQHI were derived from multi-variable Poisson regression models adjusted for age group, season, region and year as categorical variables.

Table 4. Predicted daily average rates and daily counts for use of asthma health services according to AQHI (Air Quality Health Index) levels

Asthma Morbidity Measures	AQHI =3 (Low Health Risk)		AQHI =6 (Moderate Health Risk)			AQHI =10 (High Health Risk)		
	Predicted Rate[a]	Expected Number[b]	Predicted Rate	Expected Number	Percent Difference[c]	Predicted Rate	Expected Number	Percent Difference
Asthma Outpatient Visits	1.498	2278	1.763	2681	17.7%	2.190	3330	46.2%
Asthma ED Visits	0.106	160	0.106	162	0.8%	0.108	164	2.0%
Asthma Hospital Admissions	0.013	20	0.014	22	6.4%	0.016	24	15.7%

[a] Predicted daily average rates were obtained from the adjusted Poisson regression models with age, season, region and year held at their mean values.

[b] Expected counts were calculated by multiplying the predicted rates to the average asthma prevalence (in the example above, we used the Ontario 1.5 million asthma prevalence population for illustration).

[c] Percent difference compared to AQHI=3.

Table 5. Summary of studies examining the association between air quality measures and asthma

Year of Publication	Study	Data Collection Period	Location	Study Population	Sample Size	Outcomes	Air Quality Measures	Findings
1998	Burnett et al.	1980-1991	11 Canadian cities	All ages	816,991	Mortality of non-accidental causes	SO_2, NO_2, O_3, CO	All pollutants were significantly associated with mortality; NO_2 had the strongest association
2008	Stieb et al.	1981-2000	12 Canadian cities	All ages	NA	Overall mortality	AQHI, SO2, NO2, O3, CO, PM10, PM2.5	Each unit increase in AQHI was associated with an increase of 1.2% in mortality
2002	Stieb et al.	1985-2000	Worldwide	All ages	109 studies	All-cause, respiratory mortality	SO_2, NO_2, O_3, CO, PM_{10}	Acute air pollution exposure was significantly associated with mortality; stronger associations with respiratory mortality for all pollutants except O_3
2010	Weinmayr et al.	1990-2008	Europe, US, other	0-18 years	36 studies	LRS, cough, PEF of children with asthma	NO_2, PM_{10}	PM_{10} was significantly associated with asthma symptom episode; NO_2 was significantly associated with asthma symptoms in overall analysis only considering all possible lags
2009	Stieb et al.	1992-2003	7 Canadian cities	All ages	83,563 (asthma); 125,145 (respiratory)	ED visits for asthma and respiratory infection	SO_2, NO_2, O_3, CO, PM_{10}, $PM_{2.5}$	Ozone was associated with visits for respiratory conditions; $PM_{2·5}$ and PM_{10} were associated with asthma visits in warm season
2005	Lin et al.	1998-2001	Toronto, Canada	0-14 years	6,782	Hospitalization for respiratory infection	SO_2, NO_2, O_3, CO, PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$	All PM fractions and NO_2 were significantly associated with hospital admissions for respiratory infections
2012	Current Study	2003-2006	Province of Ontario, Canada	All ages	1·5 million (asthma)	Outpatient, ED visits	AQHI, NO_2, O_3, $PM_{2.5}$	AQHI was significantly associated with asthma morbidity on the current day and 1-2 days prior

Note: AQHI = Air Quality Health Index; SO_2 = sulphur dioxide; NO_2 = nitrogen dioxide; O_3 = ground-level ozone; CO = carbon monoxide; PM_{10} = thoracic particulate matter; $PM_{2·5}$ = fine particulate matter; $PM_{10-2.5}$ = coarse particulate matter; ED = emergency department.

Figure Legends

Figure 1. Asthma health services rate ratios (RR) by AQHI and lags stratified by age groups

Footnote: All health services rate ratios were derived from multi-variable Poisson regression models adjusted for season, region and year. The AQHI specific RRs were per unit increase in AQHI.

Figure 2. Asthma health services rate ratios (RR) by AQHI and lags stratified by seasons

Footnote: All health services rate ratios were derived from multi-variable Poisson regression models adjusted for age, region and year. The AQHI specific RRs were per unit increase in AQHI.

Figure 1.

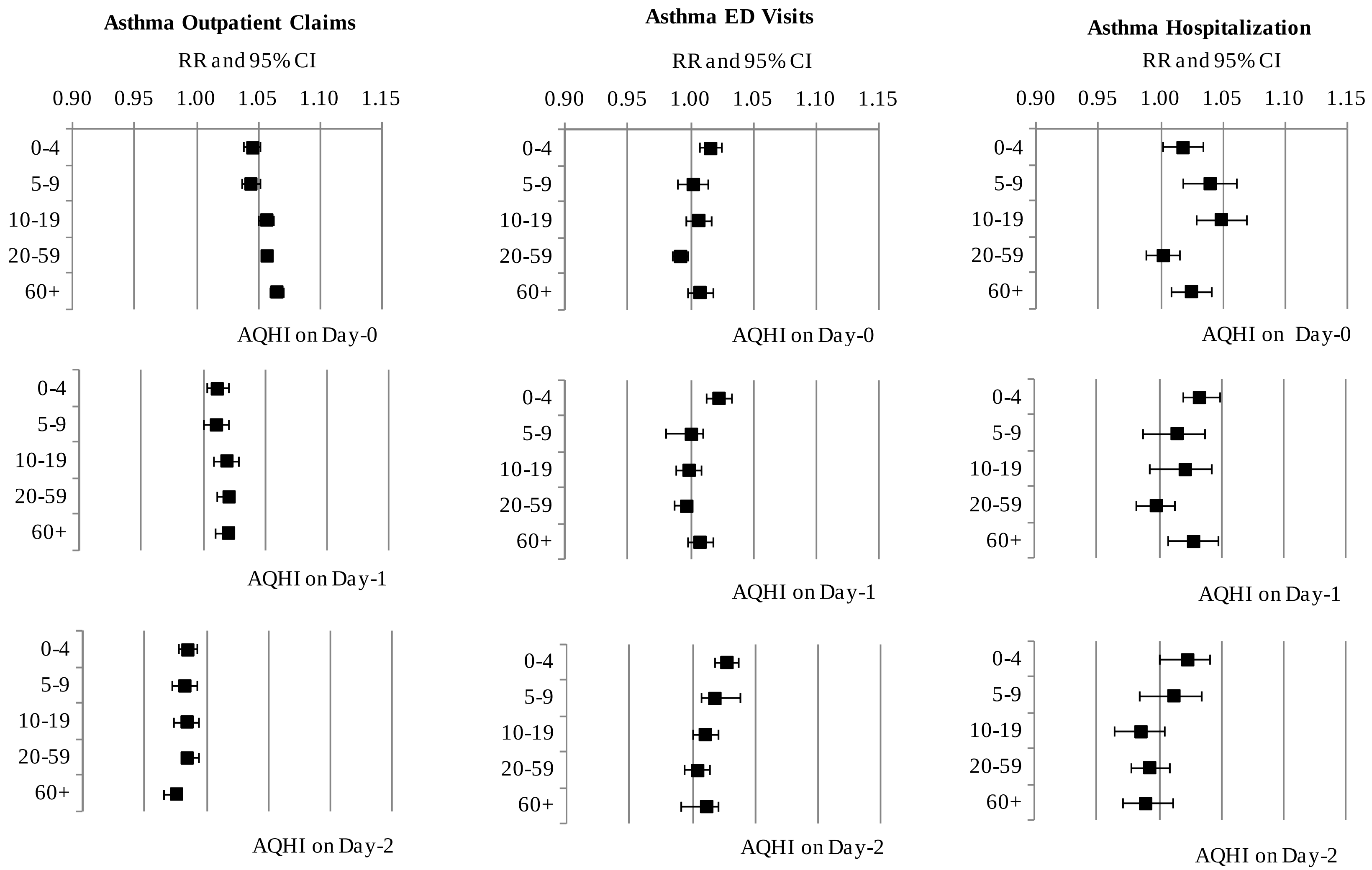
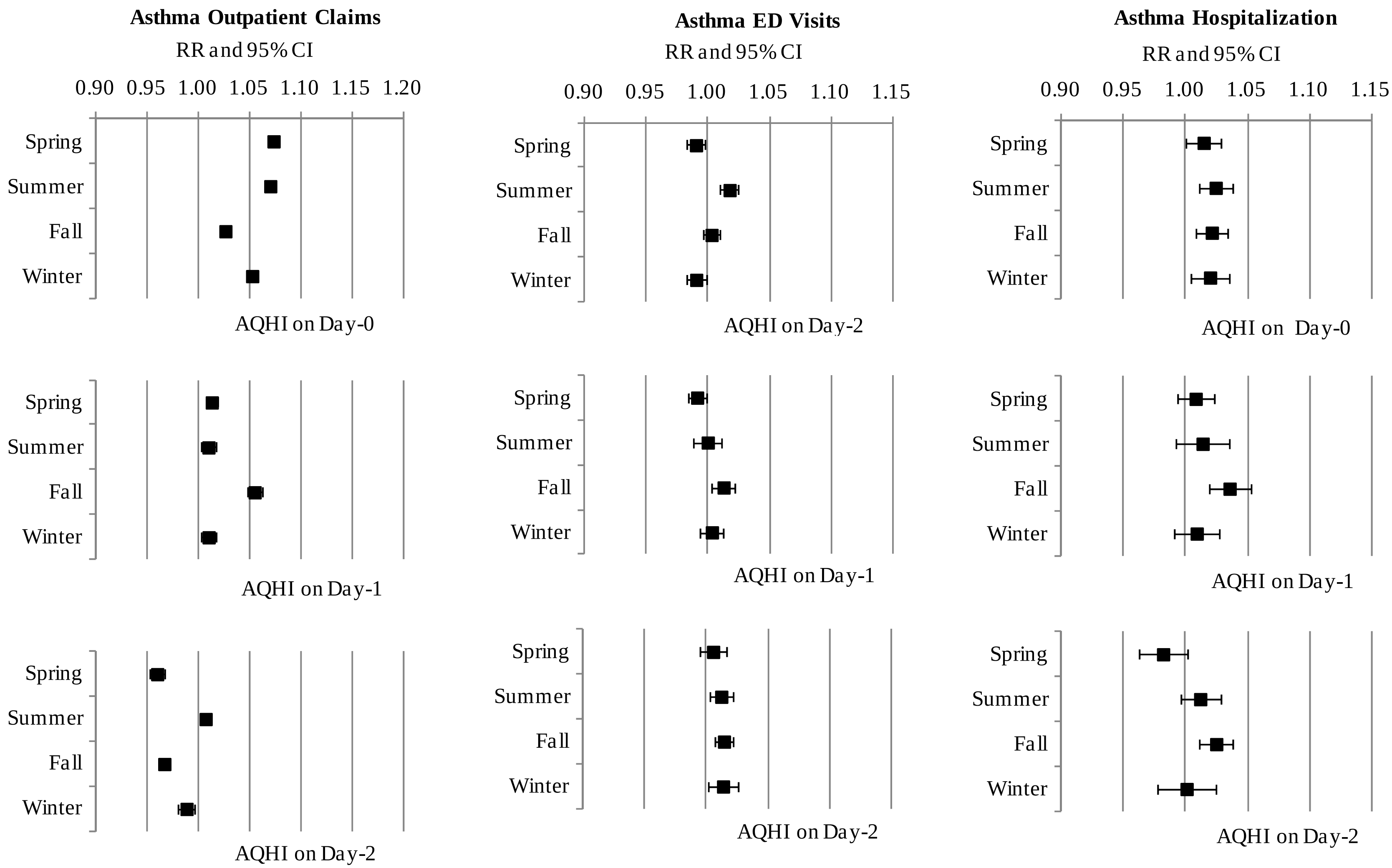

Asthma Outpatient Claims
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15
0-4
5-9
10-19
20-59
60+
AQHI on Day-0
AQHI on Day-1
AQHI on Day-2
Asthma ED Visits
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15
AQHI on Day-0
AQHI on Day-1
AQHI on Day-2
Asthma Hospitalization
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15
AQHI on Day-0
AQHI on Day-1
AQHI on Day-2

Figure 2.


Asthma Outpatient Claims
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15 1.20
Spring
Summer
Fall
Winter
AQHI on Day-0
AQHI on Day-1
AQHI on Day-2
Asthma ED Visits
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15
AQHI on Day-2
AQHI on Day-1
AQHI on Day-2
Asthma Hospitalization
RR and 95% CI
0.90 0.95 1.00 1.05 1.10 1.15
AQHI on Day-0
AQHI on Day-1
AQHI on Day-2