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Health risk of air pollution on people living with major chronic diseases: a Canadian population-based study

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ABSTRACT

Objectives: The objective of this study was to use health administrative and environmental data to quantify the effects of ambient air pollution on health service use among those with chronic diseases. We hypothesised that health service use would be higher among those with more exposure to air pollution as measured by the Air Quality Health Index (AQHI).

Setting: Health administrative data was used to quantify health service use at the primary (physician office visits) and secondary (emergency department visits, hospitalisations) level of care in Ontario, Canada.

Participants: We included individuals who resided in Ontario, Canada, from 2003 to 2010, who were ever diagnosed with one of 11 major chronic diseases.

Outcome measures: Rate ratios (RR) from Poisson regression models were used to estimate the short-term impact of incremental unit increases in AQHI, nitrogen dioxide (NO_2; 10 ppb), fine particulate matter ($PM_{2.5}$; 10 μg/m^3) and ozone (O_3; 10 ppb) on health services use among individuals with each disease. We adjusted for age, sex, day of the week, temperature, season, year, socioeconomic status and region of residence.

Results: Increases in outpatient visits ranged from 1% to 5% for every unit increase in the 10-point AQHI scale, corresponding to an increase of about 15 000 outpatient visits on a day with poor versus good air quality. The greatest increases in outpatient visits were for individuals with non-lung cancers (AQHI:RR=1.05; NO_2:RR=1.14; p<0.0001) and COPD (AQHI:RR=1.05; NO_2:RR=1.12; p<0.0001) and in hospitalisations, for individuals with diabetes (AQHI:RR=1.04; NO_2: RR=1.07; p<0.0001) and COPD (AQHI:RR=1.03; NO_2: RR=1.09; p<1.001). The impact remained 2 days after peak AQHI levels.

Conclusions: Among individuals with chronic diseases, health service use increased with higher levels of exposure to air pollution, as measured by the AQHI. Future research would do well to measure the utility of targeted air quality advisories based on the AQHI to reduce associated health service use.

Strengths and limitations of this study

- Use of a large population-based data set and inclusion of multiple major chronic diseases and conditions over an 8-year period.
- Exposure measurements were captured by multiple monitoring stations on an hourly basis, providing a thorough data set of air quality and pollutants.
- Use of fixed exposure monitoring sites to infer exposures of individuals across relatively large geographic areas (Local Health Integration Networks) may lead to potential misclassification of exposure.
- Lack of individual level data may have overestimated or 'double counted' health service use among individuals with more than one chronic disease or when individuals were admitted to hospital through the emergency department and were counted as both the emergency department and hospital admission encounters.
- We have not analysed other pollutants, such as carbon monoxide and sulfur dioxide, which may be important morbidity factors in certain regions.

INTRODUCTION

Air pollution poses measurable adverse health effects across populations and thus, is increasingly identified as a significant public health issue. The Air Quality Health Index (AQHI) is a composite measure of air quality (nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$) and ozone (O_3)), specifically developed to measure the impact of air pollution on human health.[1–3] Previous research has used population-based data to examine the short-term impact of air pollution on asthma-related morbidity and has shown an association between increased daily maximum AQHI and increased asthma health services use on the same day and on the following 2 days.[1]

The impact of air pollution on health service use is relatively well defined for pulmonary and cardiovascular disease; however, the acute effects in individuals with other chronic conditions are less well known. Recent studies have suggested that other

chronic diseases may also be aggravated by air pollution, including chronic obstructive pulmonary disease (COPD), cardiovascular disease (including heart attack and stroke), cancer and diabetes.[4–12] The objective of this study was to use the AQHI to quantify the impact of exposures to poor air quality on short-term morbidity measured by health service use for individuals with 11 major chronic diseases. Quantifying effects of ambient air pollution on health service use in vulnerable populations with chronic diseases will assist in informing public policy on air quality standards.

METHODS
Study population
We used health administrative data from Ontario, Canada—a province with a diverse multicultural population of approximately 13 million in 2010 and universal health system access for all residents. We included individuals aged 0–99 years if they had ever been diagnosed with any of these 11 chronic diseases: asthma, COPD, diabetes, hypertension, angina, acute myocardial infarction, ischaemic heart disease, congestive heart failure, stroke, lung cancer and non-lung cancers. We used previously validated algorithms with International Classification of Disease codes to identify these diseases and conditions (see online supplementary material, S1).

Exposure measures: air quality
The Ontario Ministry of the Environment and Climate Change provided hourly AQHI and air pollutant measures (NO_2, $PM_{2.5}$, O_3) from 1 January 2003 to 31 December 2010; these air quality measurements were collected by 42 fixed-site air quality monitors located across 33 cities in 14 Local Health Integration Networks in Ontario, administered by the Ministry of the Environment and Climate Change. These monitors made continuous measurements of common air pollutants near real time. Online supplementary material, S2 provides details about quality control conducted by the Ministry of the Environment and Climate Change. The AQHI is calculated using the following formula:

$$AQHI = 10/10.4 \times (100 \times (\exp(0.000871 \times NO_2) - 1$$
$$+ \exp(0.000537 \times O_3) - 1$$
$$+ \exp(0.000487 \times PM_{2.5}) - 1))$$

Units are parts per billion (ppb) for NO_2 and O_3, and micrograms per cubic metre ($\mu g/m^3$) for $PM_{2.5}$.[13] The AQHI presents a simple scale ranging from 1 to 10+ where 1 represents good air quality and a low health risk, and 10 represents poor air quality and a high-health risk (see online supplementary material, S2).We calculated daily 1 h maximum values of AQHI, NO_2, $PM_{2.5}$ and O_3 for each Local Health Integration Network. One-hour maximum values were used, as it has been suggested in the literature that these provide the most

significant results when predicting short-term health effects, compared to mean and median values.[14]

Outcome measures: health services use
We used total daily all-cause health service use to measure acute health morbidities for individuals with chronic diseases. We obtained these data from four health administrative databases housed at the Institute for Clinical Evaluative Sciences: the Ontario Health Insurance Plan Database contains information on fee-for-service billings for physician services rendered; the National Ambulatory Care Reporting System contains data for emergency department visits; the Canadian Institute for Health Information Discharge Abstract Database records the primary and secondary diagnoses for all hospitalisations; the Ontario Registered Persons Database includes information on sex, birth date and region of residence. We calculated all-cause rates of health service use per 1000 disease-specific populations.

Definition of covariates
We adjusted for potential confounding variables in our multivariable analysis. These variables included age group (10-year age groups), sex, region of residence, socioeconomic status, day of the week, temperature, season and year of data (2003–2010). We examined individuals aged 20+ years in all analyses; however, we also included individuals aged 0–19 years in the analysis of asthma and diabetes, excluded those aged under 30 years in the analysis of COPD and excluded those aged under 40 years in the analysis of congestive heart failure (see details in online supplementary materials, S1). We categorised region of residence according to Local Health Integration Network. We inferred socioeconomic status from neighbourhood income quintiles, based on census data. We categorised seasons as follows: spring (March to May), summer (June to August), fall (September to November) and winter (December to February). There was less than 0.5% missing data in demographic variables and 10% in income quintiles; missing categories were excluded from the regression analyses. Missing daily temperatures (less than 1%) were substituted by the mean temperature of the respective month.

Statistical analysis
We calculated yearly distributions of the daily maximum values of the AQHI and pollutants, as well as prevalence and health service use for the chronic diseases from 2003 to 2010. We used Poisson regressions to examine the associations between air quality and health service use; we examined immediate effects with a time lag of 0, 1 and 2 days. The unit of analysis for health service use was the number of outpatient claims or emergency department or hospital admissions on day 0. We included offset terms for the disease-specific populations and adjusted for confounders. We used rate ratios (RR)

with p values to calculate the risk of short-term disease-specific health service use associated with acute exposure to poor air quality.[15] We checked for overdispersion and violations of Poisson assumptions by plotting residuals versus mean exposure level.[15] We used Pearson's χ^2 test to assess model goodness-of-fit. To calculate the expected increase in health service use on days with an AQHI of 3, 6 and 10 (chosen based on AQHI health advisory category cut-points for low risk, medium risk and high risk, respectively), we multiplied the disease-specific daily average health service use rates from the Poisson models by the average disease prevalence. We used SAS V.9.2 (SAS Institute Inc, Cary, North Carolina, USA) to perform the analyses.[16]

RESULTS
Air quality trend
The distributions of the mean daily maximum AQHI, NO_2, $PM_{2.5}$ and O_3 by year and season are shown in online supplementary material, table S3. For 2003–2010, average measures±SDs were AQHI: 3.45±1.19, NO_2: 24.39±12.41 ppb, $PM_{2.5}$: 13.93±9.53 μg/m^3 and O_3: 39.57 ±14.15 ppb, with a general improvement in all air quality metrics over time. Air quality and pollutant values varied seasonally: AQHI was highest in the spring (3.79±1.09) and lowest in the fall (3.02±1.13); NO_2 was highest in winter (27.98±12.58 ppb) and lowest in summer (19.71 ±10.14 ppb); $PM_{2.5}$ and O_3 were highest in summer ($PM_{2.5}$: 18.06±11.31 μg/m^3; O_3: 48.63±15.53 ppb) and lowest in winter ($PM_{2.5}$: 11.12±6.77 μg/m^3; O_3: 30.76 ±7.12 ppb). Air quality and air pollutant values also differed by geographic region, with Ontario's smallest and most populous Local Health Integration Network having the highest average AQHI (4.05±1.27) and NO_2 (33.18

±12.18 ppb), while Ontario's largest and least populous Local Health Integration Network had the lowest average AQHI (2.87±0.92), $PM_{2.5}$ (10.57±7.04 μg/m^3) and O_3 (35.98±9.85 ppb).

Distributions of chronic diseases and morbidities
Table 1 shows the distributions of the chronic diseases and associated all-cause health service use per 1000 disease population. Hypertension (24.9%) and asthma (13.3%) had the highest disease prevalence. Individuals with lung cancer had the highest emergency department visits and hospitalisation rates (209.6 and 330.6 per 1000, respectively), while individuals with diabetes had the highest outpatient visit rate (2805.9 per 1000). Chronic disease prevalence rates from 2003 to 2010 are presented in online supplementary material, figure S5.

Associations of air quality measures and disease morbidities
Table 2 and figure 1 show the results of the disease-specific multivariable Poisson regressions that modelled the association between AQHI, air pollutants and health service use on day 0 of exposure (see day 1 and 2 of exposure in online supplementary material, table S4a and S4b). The risk of individual pollutant was adjusted for the presence of other pollutants. None of the regression models violated model assumptions. Overall, the increase in the rate of outpatient visits for each unit increase in the same-day AQHI and each unit (10-ppb) increase in daily maximum NO_2 (adjusted for $PM_{2.5}$ and O_3) varied from 1% to 14%. Those with non-lung cancers (AQHI: RR=1.05; NO_2:RR=1.14) or COPD (AQHI:RR=1.05; NO_2: RR=1.12) had the greatest increase in same-day outpatient visits. Increase in rate of same-day hospitalisation was highest among those with diabetes (AQHI RR=1.04;

Table 1 Descriptive statistics of chronic diseases and health services use, Ontario, averaged over 2003–2010

Disease categories	Number ever Diagnosed†		Health services use* Outpatient visits		ED visits		Hospital admissions	
	N	Rate‡	N	Rate*	N	Rate*	N	Rate*
Hypertension	2 395 192	24.9	3 625 230	1513.5	38 146	15.9	21 089	8.8
Asthma	1 690 973	13.3	842 305	498.1	62 599	37.0	6 713	4.0
Non-lung cancers	1 096 599	11.4	1 985 132	1810.3	27 245	24.8	73 834	67.3
Angina	946 575	9.8	475 448	502.3	17 855	18.9	11 181	11.8
Diabetes	915 458	7.2	2 568 707	2805.9	147 385	161.0	17 461	19.1
Chronic obstructive pulmonary disease (COPD)	615 540	7.8	495 663	805.2	36 868	59.9	21 334	34.7
Stroke	450 315	4.7	665 649	1478.2	16 214	36.0	12 658	28.1
Congestive heart failure	212 790	3.5	444 022	2086.7	28 561	134.2	19 017	89.4
Ischaemic heart disease	204 800	2.1	304 261	1485.7	5 253	25.7	26 930	131.5
Acute myocardial infarction	147 939	1.5	95 695	646.9	6 678	45.1	21 089	142.6
Lung cancer	16 711	0.2	2 121	126.9	3 503	209.6	5 525	330.6

*All-cause health services utilisation rate per 1000 disease-specific prevalent population.
†Asthma and diabetes included all ages; COPD ages 30+ years, chronic heart failure ages 40+ years, all others 20+ years.
‡Rate per 100 population.
ED, emergency department.

Table 2 Risk of health services use (claim or admission) by AQHI and pollutants on day 0 of exposure; each pollutant is adjusted for the other two pollutants

Disease categories (In alphabetical order)	Outpatient visits				ED visits				Hospitalisations			
	Rate ratio*	$L_{95\%}$	$U_{95\%}$	p Value	Rate ratio*	$L_{95\%}$	$U_{95\%}$	p Value	Rate ratio*	$L_{95\%}$	$U_{95\%}$	p Value
Acute myocardial infarction												
AQHI	0.97	0.96	0.97	<0.0001	0.94	0.94	0.94	<0.0001	0.96	0.96	0.97	<0.0001
NO_2	1.02	1.02	1.02	<0.0001	0.98	0.98	0.98	<0.0001	1.06	1.06	1.06	<0.0001
$PM_{2.5}$	0.96	0.96	0.96	<0.0001	0.95	0.95	0.96	<0.0001	0.94	0.93	0.94	<0.0001
O_3	0.98	0.97	0.98	<0.0001	0.98	0.98	0.99	<0.0001	0.96	0.96	0.96	<0.0001
Angina												
AQHI	1.04	1.04	1.04	<0.0001	1.01	1.00	1.01	0.0001	1.03	1.02	1.03	<0.0001
NO_2	1.12	1.12	1.12	<0.0001	1.02	1.01	1.02	<0.0001	1.08	1.08	1.09	<0.0001
$PM_{2.5}$	0.95	0.95	0.95	<0.0001	0.99	0.99	0.99	<0.0001	0.96	0.96	0.97	<0.0001
O_3	0.98	0.98	0.98	<0.0001	1.00	0.99	1.00	0.0179	0.99	0.98	0.99	<0.0001
Asthma												
AQHI	1.03	1.03	1.03	<0.0001	0.99	0.99	0.99	<0.0001	1.01	1.00	1.01	<0.0001
NO_2	1.06	1.06	1.07	<0.0001	0.99	0.98	0.99	<0.0001	1.03	1.02	1.03	<0.0001
$PM_{2.5}$	0.98	0.98	0.98	<0.0001	1.01	1.01	1.01	<0.0001	0.97	0.97	0.98	<0.0001
O_3	0.98	0.98	0.99	<0.0001	1.00	1.00	1.00	0.7534	1.01	1.01	1.01	<0.0001
Non-lung cancers												
AQHI	1.05	1.05	1.05	<0.0001	0.99	0.99	1.00	<0.0001	1.03	1.02	1.03	<0.0001
NO_2	1.14	1.14	1.14	<0.0001	1.00	1.00	1.00	0.5871	1.11	1.10	1.11	<0.0001
$PM_{2.5}$	0.94	0.94	0.95	<0.0001	1.00	0.99	1.00	0.3745	0.94	0.94	0.95	<0.0001
O_3	0.98	0.98	0.98	<0.0001	0.99	0.99	1.00	<0.0001	0.98	0.98	0.99	<0.0001
Congestive heart failure												
AQHI	1.02	1.02	1.02	<0.0001	0.99	0.99	0.99	<0.0001	1.02	1.02	1.02	<0.0001
NO_2	1.08	1.08	1.08	<0.0001	1.00	1.00	1.01	0.0261	1.09	1.09	1.09	<0.0001
$PM_{2.5}$	0.96	0.96	0.96	<0.0001	1.00	1.00	1.00	0.7619	0.96	0.95	0.96	<0.0001
O_3	0.98	0.98	0.98	<0.0001	0.98	0.98	0.98	<0.0001	0.98	0.97	0.98	<0.0001
Chronic obstructive pulmonary disease (COPD)												
AQHI	1.05	1.05	1.06	<0.0001	1.00	1.00	1.01	0.0007	1.03	1.03	1.04	<0.0001
NO_2	1.12	1.12	1.12	<0.0001	1.00	1.00	1.01	0.0338	1.09	1.09	1.10	<0.0001
$PM_{2.5}$	0.97	0.96	0.97	<0.0001	1.02	1.01	1.02	<0.0001	0.96	0.96	0.97	<0.0001
O_3	0.98	0.98	0.98	<0.0001	0.99	0.99	0.99	<0.0001	0.98	0.98	0.98	<0.0001
Diabetes												
AQHI	1.03	1.03	1.03	<0.0001	1.00	1.00	1.00	0.0013	1.04	1.04	1.04	<0.0001
NO_2	1.08	1.08	1.08	<0.0001	1.00	1.00	1.00	0.3093	1.07	1.07	1.08	<0.0001
$PM_{2.5}$	0.97	0.97	0.97	<0.0001	1.01	1.00	1.01	<0.0001	0.98	0.97	0.98	<0.0001
O_3	0.99	0.99	0.99	<0.0001	1.00	1.00	1.00	0.5334	1.00	0.99	1.00	<0.0001
Hypertension												
AQHI	1.03	1.03	1.03	<0.0001	0.98	0.97	0.98	<0.0001	1.02	1.02	1.03	<0.0001
NO_2	1.08	1.08	1.08	<0.0001	1.00	1.00	1.00	0.2714	1.06	1.06	1.07	<0.0001
$PM_{2.5}$	0.97	0.97	0.97	<0.0001	0.99	0.98	0.99	<0.0001	0.98	0.97	0.98	<0.0001
O_3	0.98	0.98	0.99	<0.0001	0.98	0.98	0.98	<0.0001	0.99	0.99	0.99	<0.0001
Ischaemic heart disease												
AQHI	1.02	1.02	1.02	<0.0001	1.00	1.00	1.00	0.8059	0.98	0.98	0.98	<0.0001
NO_2	1.05	1.05	1.05	<0.0001	1.00	1.00	1.00	0.8365	1.05	1.05	1.06	<0.0001
$PM_{2.5}$	0.98	0.97	0.98	<0.0001	1.00	1.00	1.01	0.6955	0.94	0.94	0.95	<0.0001
O_3	0.99	0.99	0.99	<0.0001	1.00	1.00	1.00	0.3718	0.97	0.97	0.98	<0.0001
Lung cancer												
AQHI	0.99	0.98	0.99	<0.0001	0.98	0.97	0.98	<0.0001	0.96	0.96	0.97	<0.0001
NO_2	1.06	1.05	1.06	<0.0001	0.99	0.99	0.99	<0.0001	1.02	1.02	1.02	<0.0001
$PM_{2.5}$	0.94	0.94	0.95	<0.0001	0.99	0.98	0.99	<0.0001	0.95	0.95	0.96	<0.0001
O_3	0.98	0.98	0.98	<0.0001	0.99	0.98	0.99	<0.0001	0.97	0.97	0.98	<0.0001
Stroke												
AQHI	1.00	1.00	1.00	<0.0001	0.96	0.96	0.96	<0.0001	0.98	0.98	0.99	<0.0001
NO_2	1.05	1.04	1.05	<0.0001	0.99	0.99	0.99	<0.0001	1.05	1.04	1.05	<0.0001
$PM_{2.5}$	0.97	0.97	0.97	<0.0001	0.97	0.97	0.97	<0.0001	0.96	0.96	0.96	<0.0001
O_3	0.98	0.98	0.98	<0.0001	0.99	0.98	0.99	<0.0001	0.97	0.97	0.97	<0.0001

*The Risk Ratios were obtained from Poisson Regressions and these correspond to increase/decrease in risk of the respective health services use per unit increase in AQHI or per 10-unit increase in the air pollutants. All Risk Ratios were adjusted for age groups, sex, seasons, temperature, day of week, years, Local Health Integration Network and income quintiles.
$L_{95\%}$, lower bound of 95% CI; $U_{95\%}$, upper bound of 95% CI.
AQHI, Air Quality Health Index; ED, emergency department; NO_2 nitrogen dioxide; $PM_{2.5}$ fine particulate matter; O_3, ozone.
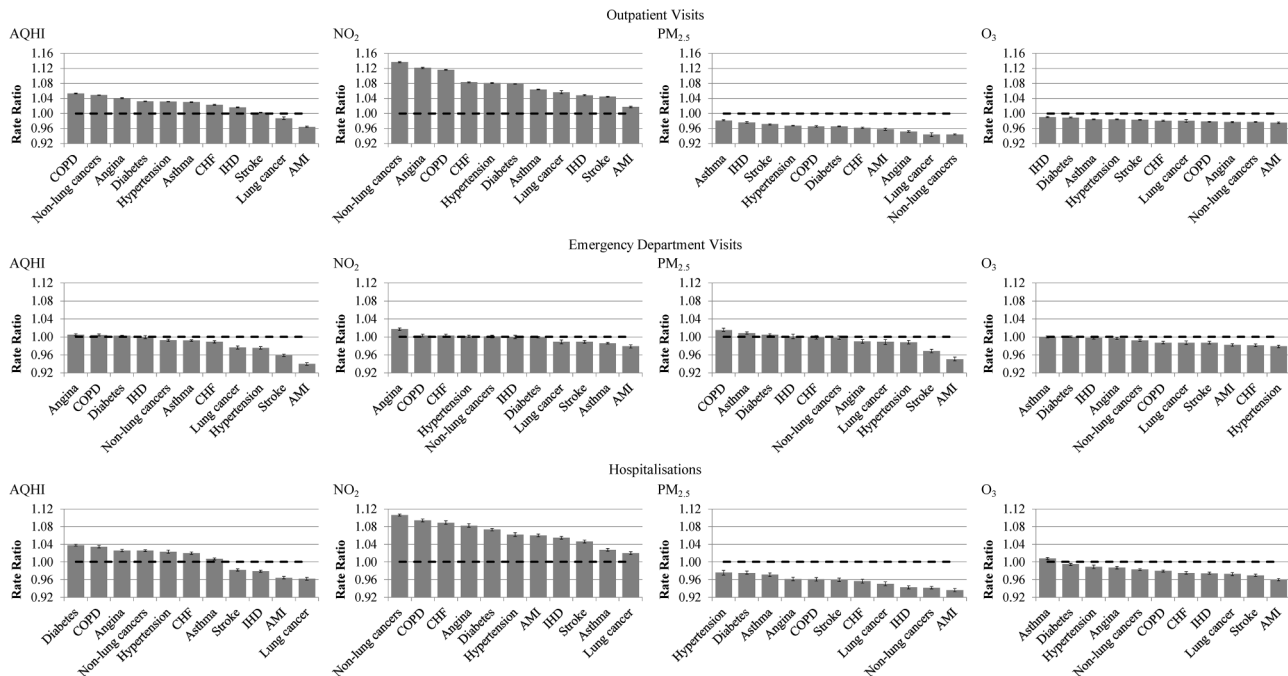
Figure 1 Risk* of health services use by pollutants on day 0 of exposure: AQHI, NO$_2$, PM$_{2.5}$ and O$_3$. * The Rate Ratios were obtained from Poisson Regressions and these correspond to increase/decrease in risk of the respective health services use per unit increase in AQHI and per 10-unit increase in each of NO$_2$, PM$_{2.5}$ and O$_3$. All Rate Ratios were adjusted for age groups, sex, day of the week, temperature, seasons, years, Local Health Integration Network and income quintiles. Error bars represent 95% CIs.

NO$_2$:RR=1.07) and COPD (AQHI RR=1.03; NO$_2$: RR=1.09). The increase in rate of same-day emergency department visits was relatively small. The impact on health service use remained 1 and 2 days after the measured peak AQHI and NO$_2$.

Table 3 shows a translation of the population data into predicted daily rates and daily expected all-cause health service use among populations with each of the chronic conditions on days with a maximum AQHI of 6 (medium health risk) or 10 (high), as compared to days with a maximum AQHI of 3 (low health risk). Given that the increase in the rate of emergency department visits was small (see table 2), we focused on the per cent change in outpatient visits and hospital admissions. The highest per cent changes in outpatient visits on a day with a maximum AQHI of 10 were predicted in COPD, non-lung cancers and angina (43.9%, 39.6% and 32.4%, respectively). The highest per cent changes in hospitalisations were predicted in diabetes, COPD and angina (29.7%, 26.7% and 19.4%, respectively). The greatest increase in expected counts of outpatient visits and hospitalisations on a day with a maximum AQHI of 10 was predicted in hypertension (3862 more expected outpatient visits) and non-lung cancers (49 more expected hospitalisations), respectively. Overall, the increase in air pollution-attributable outpatient visits comparing *moderate* and *high*-risk air quality days to *low*-risk days amounted to a total of 6052, and 15 301 visits per day, respectively.

DISCUSSION

To date, in magnitude and breadth, this is one of the largest time series analyses examining the impact of air quality on health. We examined the effects of health service use across an entire health system and we analysed all major chronic diseases over 8 years. Strategically, this study focused on the AQHI, an important national translational tool that distils the complexity of air quality science and health risk into a simple visual linear scale for individuals with chronic disease, healthcare providers and public health and environmental policymakers. This study demonstrated a consistent and quantifiable health risk based on the AQHI that may inform public health and environmental policy.

The WHO describes a pyramid of air pollution-attributable health impacts that includes subclinical effects, symptoms, health services utilisation and mortality,[17][18] and the US Environmental Protection Agency has also concluded that PM$_{2.5}$, O$_3$ and NO$_2$ are causal or likely causal factors for numerous cardiac and pulmonary health outcomes.[10–12] Plausible mechanistic pathways have been described, including enhanced coagulation/thrombosis, a propensity for arrhythmias, acute arterial vasoconstriction, systemic inflammatory responses and the chronic promotion of atherosclerosis.[19] Our findings strengthen and extend an understanding of the acute impact of air pollution on chronic diseases for which there is limited published evidence, in particular for diabetes, hypertension and malignancy.

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Table 3 Predicted daily health services use based on AQHI and pollutant levels

	AQHI=3 (Low-health risk)		AQHI=6 (Moderate-health risk)			AQHI=10 (High-health risk)		
	Predicted daily rate*	Expected number of visits†	Predicted daily rate*	Expected number of visits†	Per cent change‡	Predicted daily rate*	Expected number of visits†	Per cent change‡
Outpatient visits (sorted by highest to lowest expected no. of visits)								
Hypertension	5.83	15 834	6.41	17 387	9.8	7.26	19 697	24.4
Diabetes	10.72	12 236	11.79	13 450	9.9	13.37	15 258	24.7
Non-lung cancers	5.53	7 437	6.38	8 581	15.4	7.72	10 384	39.6
Asthma	1.80	3 366	1.97	3 681	9.3	2.21	4 146	23.2
Stroke	5.21	2 648	5.24	2 666	0.7	5.29	2 691	1.6
COPD	2.41	1 660	2.82	1 940	16.9	3.47	2 388	43.9
Angina	1.51	1 544	1.70	1 741	12.8	2.00	2 045	32.4
Congestive heart failure	6.19	1 412	6.63	1 512	7.1	7.26	1 657	17.4
Ischaemic heart disease	5.18	1 138	5.43	1 193	4.9	5.79	1 271	11.8
Acute myocardial infarction	1.88	307	1.69	276	−10.3	1.46	238	−22.4
Lung Cancer	0.46	9	0.45	8	−3.8	0.42	8	−8.5
Hospitalisations (sorted by highest to lowest expected number of visits)								
Non-lung cancers	0.19	250	0.20	270	7.9	0.22	299	19.3
Ischaemic heart disease	0.44	97	0.42	91	−6.1	0.38	84	−13.6
Diabetes	0.06	73	0.07	82	11.8	0.08	95	29.7
COPD	0.09	64	0.10	71	10.7	0.12	81	26.7
Acute myocardial infarction	0.40	65	0.36	59	−10.3	0.31	51	−22.4
Congestive heart failure	0.24	54	0.25	58	6.1	0.27	63	14.8
Stroke	0.09	47	0.09	44	−5.3	0.08	41	−11.8
Angina	0.03	32	0.03	34	7.9	0.04	38	19.4
Asthma	0.01	21	0.01	22	2.0	0.01	22	4.8
Lung Cancer	1.03	20	0.92	17	−11.0	0.79	15	−23.7
Hypertension	0.00	7	0.00	8	7.2	0.00	9	17.5

*Predicted daily average rates per 1000 population were obtained from the adjusted Poisson regression models.
†Expected counts were calculated by multiplying the predicted rates to the average disease prevalence (we used the Ontario disease-specific prevalence population presented in table 1).
‡Per cent change is calculated as compared to when AQHI=3.
AQHI, Air Quality Health Index; COPD, chronic obstructive pulmonary disease.

Hypertension remains the worldwide leading risk factor for mortality. A number of studies have reported associations between air pollutants and hypertension, as well as between air pollutants and diabetes incidence and prevalence;[20–24] however, few have demonstrated its impact on health-related morbidity. Szyszkowicz[25] used a large administrative database in Canada, and measured the association between ambient air pollution and hypertension presentations to emergency department visits during a 10-year period. They reported significantly elevated risks of emergency department visits (4–6%) up to 3–6 days after peaked exposures to PM_{10}, $PM_{2.5}$, NO_2 and SO_2. Similarly, our study showed an 8% increase in same-day physician visits per 10 ppb increase in same-day peak NO_2, the fifth highest ratio observed after non-lung cancers, angina, COPD and congestive heart failure. This finding may indicate that modest elevations in air pollutants worsen blood pressure control, consequently leading to higher outpatient health service use or alternatively, that hypertension is a sensitive surrogate marker for multiple comorbidities.

Despite a compelling body of literature confirming the health risk of various air pollutants on individuals with chronic disease, these risks are underappreciated by patients and seldom acted on by clinicians.[26] The complexities of communicating air quality, its associated health risks, and actionable risk-reduction messages may be contributing to low physician and patient uptake. Our study extends prior research by evaluating a new method of reporting and advising clinicians and patients about air quality and its risks: the AQHI. The AQHI was designed to create a more direct link between air quality and health, and to present the index in a format that could easily communicate risk reduction to the general population.[27] Using a format similar to the ultraviolet ray index that the general public is familiar with, the AQHI 'translates' air quality on a scale of 1–10 and attaches specific risk-reduction health messages. Hong Kong, with the number of air pollution-related deaths ranked eighth highest out of 193 countries in the world,[28] has recently adopted AQHI for real-time monitoring and reporting. In December 2013, AQHI was commissioned by the Hong Kong government and a free smartphone AQHI application was made available from iTunes.[29] Similar scalable communication strategies are being executed in Canada. The effectiveness of these strategies remains to be determined.

This study has several strengths, namely the use of a large population-based data set and inclusion of multiple major chronic diseases and conditions over an 8-year period. To date, very few published studies are of comparable magnitude. The use of large sample sizes allowed Poisson regression models to be fully adjusted for multiple potential confounders. Furthermore, exposure measurements were captured by multiple monitoring stations on an hourly basis, providing a thorough data set of air quality and pollutants. Our study also calculated the predicted daily rate and expected volume of health services use. These rates can be used by others to generate their respective expected health service use counts based on their local disease-specific prevalence population.

A few limitations are worth noting. First, the use of fixed exposure monitoring sites to infer exposures of individuals across relatively large geographic areas (Local Health Integration Networks) may lead to potential misclassification of exposure—namely, the Berkson error. However, it has been shown that with exposure measured on a numerical scale, it leads to minimal bias in regression.[30] Our study used large population data; the CIs remained narrow and the loss of power was minimal. Second, the lack of individual level data may have overestimated or 'double counted' health service use among individuals with more than one chronic disease or when individuals were admitted to hospital through the emergency department and were counted as both the emergency department and hospital admission encounters. The low proportionate rate of hospitalisation in this study was small, suggesting that this impact was minimal. Finally, in our analysis of the AQHI, we have not analysed other pollutants, such as carbon monoxide and sulfur dioxide, which may be important morbidity factors in certain regions.

Future directions would do well to explore the role that comorbidities play in the relationship between exposure to air pollution and health service use. Further, it would be interesting to study the effects of air pollution on health service use among those who are revisiting the healthcare system for a disease or condition that they already have, compared to those who are being diagnosed for a new disease or condition.

CONCLUSION

This study suggests that air pollution exposure should be considered a risk factor for acute health morbidities among people with certain common chronic diseases. Timely AQHI air quality advisories with integrated risk reduction messages may lead to reduced morbidity associated with acute exposures to air pollution in individuals living with chronic diseases; the AQHI may also be useful in guiding public health and environmental health policy by accurately and consistently quantifying the health impacts of air pollution.

Competing interests None declared.

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Data sharing statement No additional data are available.

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