AIR POLLUTION AND EMERGENCY DEPARTMENT VISITS FOR ISCHEMIC HEART DISEASE IN MONTREAL, CANADA

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Abstract

Objectives: We examined the associations between emergency department (ED) visits for ischemic heart disease (IHD) and short-term elevations in ambient air pollutants (CO and NO₂).

Materials and Methods: A hierarchical clusters design was used to study ED visits (n = 4,979) for ischemic heart disease (ICD-9: 410–414) that occurred at a Montreal hospital between 1997 and 2002. The generalized linear mixed models technique was applied to create Poisson models for the clustered counts of ED visits for IHD. The analysis was done by gender for two age categories, all patients and patients aged over 64 years. Results: The results are presented as an excess risk increase associated with the interquartile range (IQR) of daily average of the pollutant concentration. The results for NO₂ (IQR = 9.5 ppb) were 5.9% (95% CI: 2.1–9.9) for all patients and 6.2% (95% CI: 1.2–11.4) for males; for patients aged over 64: 7.1% (95% CI: 2.5–11.9) for all patients, 9.1% (95% CI: 2.8–15.7) for males, and 6.5% (95% CI: 0.7–12.7) for females (for exposure lagged by 1-day). The results for CO (IQR = 0.2 ppm): 5.4% (95% CI: 2.3–8.5) for all patients, and 7.5% (95% CI: 3.6–11.6) for males. For patients aged over 64 years, 4.9% (95% CI: 1.3–8.7) for all patients, and 7.5% (95% CI: 2.6–12.6) for males. The results show the associations for the same day exposures. Conclusions: The short-term effects of nitrogen dioxide and carbon monoxide are associated significantly with daily ED visits for ischemic heart disease. For NO₂ the associations are stronger for patients aged over 64 years. As indicated by our results, it is likely that vehicular traffic, a producer of NO₂ and CO, contributes to an increased number of ED visits for IHD.

Key words: Ischemic heart disease, Emergency department visit, Air pollution, Relative risk

INTRODUCTION

In our study we analyzed emergency department (ED) visits for ischemic heart disease (IHD). The number of these visits depends on many factors. In general, we assumed that ED visits for IHD are related to environmental conditions, such as ambient air pollution and weather. We formulated a hypothesis that the weather conditions and ambient air pollution can affect the number of ED visits for this condition.

As ambient air pollution factors we considered nitrogen dioxide (NO₂) and carbon monoxide (CO). The statistical models were fitted with a single pollutant, temperature, and relative humidity for their current and 1-day lagged values.

Ischemic heart disease is any condition in which heart muscle is damaged or works inefficiently because of an absence or relative deficiency of its blood supply. Over the past 20 years, many epidemiological studies reported acute associations between ambient air pollution levels and increased number of deaths, hospitalizations, and emergency department visits due to cardiovascular diseases [1–11]. To be more specific, Mann et al. [7] reported that after adjustment for day of the week, study year, and smoothing splines for day of the study, temperature, and relative humidity, CO and NO₂ were both associated with
hospital admissions for IHD with the greatest effect for CO. Lin et al. [11] used a generalized additive Poisson regression to fit the logarithm of the expected values of total ED visits due to angina or acute myocardial infarction, controlling for smooth functions of season and weather and indicators for days of the week. As they reported, all investigated pollutants were positively associated with ischemic cardiovascular disease ED visits, and the time lags were relatively short, but only CO exerted the effect that was statistically significant. The interquartile (IQR) range increase in CO was associated with a 6.4% increase (95% CI: 0.7–12.1) in daily angina or acute myocardial infarction ED visits. Lee et al. [12] studied the association between air pollution and hospital admissions for IHD among individuals older than 64 years in Seoul, Korea. Their results estimated relative risk (RR) of hospitalization associated with the IQR at: 1.08 (95% CI: 1.03–1.14) for nitrogen dioxide (IQR = 14.6 ppb) and 1.07 (95% CI: 1.01–1.13) for carbon monoxide (IQR = 1.0 ppm). In this paper we report the excess risk (%RR) to represent the effects of the pollutant (%RR = (RR-1)*100%).

MATERIALS AND METHODS

Study population
The Jewish General Hospital in Montreal provided data on emergency department visits between January 1, 1997 and December 31, 2002. ED visits for ischemic heart diseases were identified based on a discharge diagnosis using the International Classification of Diseases 9th revision (ICD-9), categories 410–414 [13]. The visits were date-tagged on the day of arrival to the ED. In total, the analysis was based on 4979 ED visits for IHD over a span of 2191 days. This represented approximately 1.5% of all 340 286 recorded and diagnosed ED visits to this hospital over the study period.

Meteorological data
The Environment Canada supplied data for selected weather variables that were recorded and available hourly. In this study, the used meteorological variables were relative humidity, atmospheric pressure (sea level), and temperature (dry bulb). The daily mean as an average of hourly readings (24 measurements) was used to represent the values of the weather parameters. In the final study, only the daily mean of temperature and relative humidity were used.

Air pollution data
The data on ambient air pollution were also supplied by the Environment Canada and included NO₂ and CO. Daily mean values of pollutant levels as an average of hourly readings were used to represent shared exposure of the study population. Weather factors and ambient air pollutants were considered as current day exposure, and 1-day lagged exposure.

Statistical methods
To relate short-term effects of weather conditions and air pollutants to the number of daily IHD emergency department visits we applied a multilevel modeling methodology. We first defined clusters for available data. The clusters can be constructed in many different (and reasonable) ways. Here we proposed to cluster the data by days of the week. Such an approach allowed us to unify the week day effects on the number of ED visits and to adjust for weakly periodicity. The cluster structures absorb seasonal cycles and trends in a time-series of visits. The clusters also group days with similar air pollution levels, where pollutants are affected by human activities related to week days. The cluster constructed in such a way may have 4 or maximum 5 observations (days). The data were grouped and analyzed according to the defined clusters. The clusters respected a hierarchical structure and dependency of days in a calendar and embedded multilevel relations: days were nested in week days, week days in months, and months in years. In this convention, days were grouped according to the specified triplet {year, month, day of the week}, which expresses hierarchical structure.

In our analysis we used a generalized linear mixed model (GLMM) methodology, which involves a technique to incorporate the clusters in the constructed models [14–16]. We considered Poisson models, which are typically used for counts. Random intercept Poisson regression model
was used to respect cluster hierarchical structures. Random effects were introduced to express dependence and unobserved heterogeneity. We assumed that each cluster may have its own value of the intercept. The levels of responses on clusters were due to different factors. We assumed that the effect of the air pollutant is the same on all clusters, thus a fixed slope option was applied in the model. We built the models with the number of IHD visits as a response and a single pollutant, temperature, and relative humidity as independent variables. The models were evaluated on the basis of obtained maximum log likelihood estimations. The analysis was conducted using the computer software R with the \texttt{glmmPQL} function [17]. This function realizes the algorithm related to the GLMM methodology. To be more specific we present one of the used models:

\begin{verbatim}
glmmPQL(fixed = DailyCounts ~ NO_2_1 + Temperature_1 + Humidity_1, 
random = list(year = ~1, month = ~1, dayofweek = ~1), family = Poisson()).
\end{verbatim}

In this model counts of daily ED visits for IHD (DailyCounts) are regressed on the levels of nitrogen dioxide (NO$_2$) exposure, temperature, and relative humidity, all lagged by one day. A Poisson regression was applied. The option "~1" in the model allows variability of intercepts among the clusters, but assumes a fixed universal slope for all clusters.

\section*{RESULTS}

The results are presented in the form of three tables and one figure. Table 1 contains the number of ED visits for IHD by age and gender. Of the 4979 total visits for IHD in the study, 56.6\% (n = 2966) occurred among males. Among all visits more than half (56.8\%) occurred among persons aged 70 and older. Between 1997 and 2002, the mean number of visits to this hospital's ED for IHD by month, ranged from 80.7 (high) in May to 60.0 (low) in February. Figure 1 represents these means by months calculated for jointly all the years. The numbers of visits by months for an individual year are also shown. We observed high number of visits in the years 1997 (January–June, September) and 1998 (January–June). The reason for the variations in the frequencies of ED visits is not known. The used statistical models adjust for the different levels of counts by allowing a random intercept and a 3-level hierarchical structure of the clusters. The percentage of total visits by days of the week changed from 11.6\% on Sundays to 14.9\% on Tuesdays (14.8\% on Fridays).

Table 2 summarizes the statistics of daily average concentrations of the considered pollutants (NO$_2$ and CO) and weather variables as well as daily ED visits for IHD.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Age group & #Visits & \% Visits & Female & Male \\
\hline
1–<20 & 2 & 0.0 & 1 & 1 \\
20–<30 & 5 & 0.1 & 0 & 5 \\
30–<40 & 61 & 1.2 & 8 & 53 \\
40–<50 & 333 & 6.7 & 76 & 257 \\
50–<60 & 705 & 14.2 & 199 & 506 \\
60–<70 & 1046 & 21.0 & 369 & 677 \\
70–<80 & 1438 & 28.9 & 635 & 803 \\
\geq80 & 1389 & 27.9 & 725 & 664 \\
Total & 4979 & 100.0 & 2013 & 2966 \\
\hline
\end{tabular}
\caption{Frequency of emergency department (ED) visits for ischemic heart disease (IHD) by age group and gender, Montreal (from January 1, 1997 to December 31, 2002).}
\end{table}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Number of emergency department visits for ischemic heart disease (IHD) at a Montreal hospital between 1997 and 2002, for individual years, and an average for all six years shown by months.}
\end{figure}
Table 2. Mean, standard deviation, minimum and maximum of daily numbers of emergency department (ED) visits for ischemic heart disease (IHD), temperature, atmospheric pressure, relative humidity and air pollutants, Montreal (from January 1, 1997 to December 31, 2002)

<table>
<thead>
<tr>
<th>Variable (unit)</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily visits (n = 4979)</td>
<td>2.3</td>
<td>1.5</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Weather parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>7.7</td>
<td>11.4</td>
<td>-24.3</td>
<td>29.2</td>
</tr>
<tr>
<td>Mean pressure (kPa)</td>
<td>101.1</td>
<td>0.8</td>
<td>98.1</td>
<td>103.8</td>
</tr>
<tr>
<td>Mean humidity (%)</td>
<td>70.7</td>
<td>12.5</td>
<td>28.5</td>
<td>100.0</td>
</tr>
<tr>
<td>Air pollutants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily mean CO (ppm)</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Daily mean NO$_2$ (ppb)</td>
<td>19.4</td>
<td>7.6</td>
<td>4.3</td>
<td>89.0</td>
</tr>
</tbody>
</table>

Table 3 represents the percentage changes in ED visits for IHD and 95% confidence intervals (95% CI) across the IQR range of exposure to selected pollutants for all patients, males and females, and for the three categories for all patients (all age groups) and for patients aged over 64 years, respectively. We obtained positive statistically significant associations for exposure to NO$_2$ and CO on the same day for all and male patients. The associations for NO$_2$ were stronger for older patients (age > 64 years). For female patients’ exposure to 1-day lagged NO$_2$ was also significant. For exposure to CO the associations were almost the same for all patients aged over 64 years.

We found statistically significant associations between emergency admissions for IHD and the same day exposure to NO$_2$ (IQR = 9.5 ppb): increased visits by 5.9% for

Table 3. Percentage change in relative risk estimates (% RR) and 95% confidence interval (95% CI) by the GLMM technique analysis in relation to emergency department (ED) visits for ischemic heart disease (IHD)

<table>
<thead>
<tr>
<th>Factors (NO$_2$)</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All patients</td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>5.9 (2.1–9.9)</td>
<td>6.2 (1.2–11.4)</td>
<td>5.6 (-0.2–11.8)</td>
</tr>
<tr>
<td>Temperature</td>
<td>4.3 (-1.2–10.1)</td>
<td>2.8 (-3.8–10.0)</td>
<td>5.8 (-2.4–14.7)</td>
</tr>
<tr>
<td>Humidity</td>
<td>2.8 (-1.2–7.1)</td>
<td>2.0 (-3.2–7.5)</td>
<td>3.8 (-2.5–10.5)</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>2.8 (-0.9–6.7)</td>
<td>0.7 (-4.2–5.8)</td>
<td>6.5 (0.7–12.7)</td>
</tr>
<tr>
<td>Temperature 1</td>
<td>3.2 (-2.3–9.0)</td>
<td>0.3 (-6.2–7.3)</td>
<td>6.8 (-1.5–15.8)</td>
</tr>
<tr>
<td>Humidity 1</td>
<td>2.2 (-1.9–6.4)</td>
<td>2.3 (-3.0–7.8)</td>
<td>1.8 (-4.3–8.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors (NO$_2$)</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All patients, age &gt; 64</td>
<td>Males, aged &gt; 64</td>
<td>Females, aged &gt; 64</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>7.1 (2.5–11.9)</td>
<td>9.1 (2.8–15.7)</td>
<td>5.1 (-1.5–12.1)</td>
</tr>
<tr>
<td>Temperature</td>
<td>7.4 (0.8–14.4)</td>
<td>4.7 (-3.7–13.7)</td>
<td>10.4 (0.7–20.9)</td>
</tr>
<tr>
<td>Humidity</td>
<td>3.5 (-1.4–8.6)</td>
<td>2.1 (-4.5–9.1)</td>
<td>5.2 (-2.0–12.9)</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>1.8 (-2.7–6.5)</td>
<td>-0.6 (-6.6–5.8)</td>
<td>5.1 (-1.5–12.1)</td>
</tr>
<tr>
<td>Temperature 1</td>
<td>3.5 (-2.9–10.2)</td>
<td>-2.2 (-9.9–6.2)</td>
<td>10.3 (0.6–20.8)</td>
</tr>
<tr>
<td>Humidity 1</td>
<td>-2.2 (-6.8–2.7)</td>
<td>-5.1 (-11.2–1.3)</td>
<td>1.8 (-5.2–9.2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors (CO)</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
<th>% RR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>5.4 (2.3–8.5)</td>
<td>7.5 (3.6–11.6)</td>
<td>2.7 (-2.0–7.6)</td>
</tr>
<tr>
<td>Temperature</td>
<td>4.3 (-1.2–10.0)</td>
<td>3.7 (-2.9–10.7)</td>
<td>4.7 (-3.3–13.5)</td>
</tr>
<tr>
<td>Humidity</td>
<td>1.5 (-2.6–5.8)</td>
<td>0.0 (-5.3–5.6)</td>
<td>3.3 (-3.2–10.1)</td>
</tr>
<tr>
<td>CO</td>
<td>2.6 (-0.5–5.8)</td>
<td>2.3 (-1.7–6.5)</td>
<td>4.0 (-0.7–8.9)</td>
</tr>
<tr>
<td>Temperature 1</td>
<td>3.2 (-2.2–8.9)</td>
<td>1.1 (-5.4–8.0)</td>
<td>5.9 (-2.2–14.8)</td>
</tr>
<tr>
<td>Humidity 1</td>
<td>1.5 (-2.6–5.8)</td>
<td>1.6 (-3.8–7.2)</td>
<td>1.0 (-5.3–7.6)</td>
</tr>
</tbody>
</table>
all patients, 6.2% for male patients, 7.1% for all patients aged over 64 years, 9.1% for males aged 65 and older; and 6.5% for female patients aged over 64 years, 7.1% for all patients, 9.1% for males aged 65 and older, and 6.5% for 1-day lagged NO\textsubscript{2} exposure. A percentage increase for IHD visits for current day exposure to CO (IQR = 0.2 ppm) was 5.4% for all patients, 7.5% for males, and for patients aged over 64 years; 4.9% for all patients, and 7.5% for males. The models also indicated statistically significant associations with the number of visits and exposure to temperature (IQR = 19.0°C). The associations with relative humidity (IQR = 17.7%) were not statistically significant.

**DISCUSSION AND CONCLUSIONS**

In this study, the short-term effect of NO\textsubscript{2} and CO exposure on daily ED visits for IHD in Montreal was found to be positive and statistically significant. Our study showed that exposure to NO\textsubscript{2} is associated with an increase in ED visits for IHD from 5.9% to 9.1%. The relationship between ED visits for IHD and an exposure to ambient CO is an increase in the number of visits from 4.9% to 7.5%. The risk estimates presented here have been adjusted for meteorological effects of temperature and relative humidity. Strictly speaking, it should be said that the obtained results did not precisely represent the relationship between IHD and the environmental conditions. They rather show the potential association between visits to emergency departments for heart problems diagnosed as IHD and the ambient air pollutants and weather factors. The study covers the cases of IHD, which forces the sufferer to seek emergency treatment. The used ED data contained only information on the age and gender of the patients. Consequently, we could not adjust them for other patient’s characteristics.

Limitations of this study are typical of this type of investigations. They include the impact of measurement error on the considered factors (exposure) and recorded (diagnosed) IHD visits. Like most other studies, our risk estimates may be biased by assigning to patients regional measures of air pollution from fixed site-monitoring stations. In this study, we used shared exposure. We assumed the same exposure for the study population. In addition to exposure misclassification, some misclassification of ED visits is also likely. The adequacy of the covariates used in the models is important as well. The used statistical method starts to be called the Polish method. The method was already used to investigate the association between ambient air pollution exposures and health outcomes [18,19]. Our findings support the hypothesis that ED visits for IHD are related to weather conditions and ambient air pollution occurring within 24 hours preceding presentations. It should be emphasized that the dependency of ED visits for ischemic heart disease on the atmospheric factors and ambient air pollutants, in this paper, is based on purely statistical results. As such, it cannot be used to prove the thesis that the atmospheric conditions and air pollution trigger IHD. On the other hand, they show that an increase in levels of ambient air pollution exposure is related to the increase in the number of visits for this condition.

Our study summarizes the relationship between ambient air pollution (NO\textsubscript{2} and CO) and ED visits for IHD in Montreal, taking into account the association between visits to emergency departments for heart problems diagnosed as IHD and the environmental conditions.
Montreal. The presented results are similar to those obtained by other authors [1–12, 20–24]. In general, the cited publications reported effects of carbon monoxide and/or nitrogen dioxide on IHD outcomes. In our study, we also found positive associations for CO and NO\textsubscript{2} with ED visits for IHD. In the papers listed in the presented references as well as in our work, the used time lags were relatively short: the same day exposure or 1-day lagged exposure. Our study adds to the growing evidence for the effects of ambient air pollution on IHD. This study has two insights, it investigated the relationships by gender and age group and applied a new methodological approach [18]. In the presented literature the researchers mainly used two statistical approaches: generalized linear models technique and case-crossover technique [25,26].

As already mentioned, we observed the elevated numbers of visits in the years 1997 (specifically in May and September) and 1998 (in May). For both years a parallel shift up in the relation to other years was observed (January–June). ED visits were classified according to the ICD-9 code for diseases. Each ED chart was coded by a nosologist using available information on a visit. Different approaches to the classification of visits may be among factors that affected the numbers of ED visits in the years 1997 and 1998. The data on daily ED visits for IHD in Montreal were retrieved by using SAS software [27]. The differences in the numbers of visits by years was not a problem in our analysis. The hierarchical structure of the clusters included year as one of the components of variations. The applied statistical method adjusted for different levels of responses by using a random intercept. In our study, the used resolution was one month, i.e., there were 4 or 5 records in one cluster (the smallest possible resolution is two weeks). As for other months, for the elevated counts in September 1997, the slopes were calculated as a function of the pollutant.

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