Journal of Public Health: From Theory to Practice (2020) 28:367–374
https://doi.org/10.1007/s10389-019-01033-z

ORIGINAL ARTICLE

Short-term exposure to ambient air pollution and acute myocardial infarction attack risk

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Received: 14 August 2018 / Accepted: 28 January 2019 / Published online: 21 February 2019

Abstract

Background It is still unclear about the association between ambient air pollution and attack risk of acute myocardial infarction (AMI) in South China. This study assessed the effects of short-term exposure to ambient air pollutants on hospital admission of AMI in Guangzhou, South China.

Materials and methods We obtained the information on 19,622 hospital admissions of AMI from the Guangzhou Cardiovascular and Cerebrovascular Disease Event Surveillance System during the years from 2014 to 2017. Daily concentrations of air pollution data on particulate matter < 2.5 μm in diameter ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) were available from the Daily Quality Report of the Guangzhou Environmental Protection Bureau during the study period. The effects of air pollution exposure on the risk of AMI hospital admission were assessed using Poisson generalized additive models. Risk estimates were reported as the percent increase in daily hospital admissions of AMI for an interquartile range (IQR) increment in air pollution concentrations.

Results On average, there were 13 hospital admissions of AMI each day. After controlling for the pollutants, including $PM_{2.5}$, SO_2, and O_3, and other time-varying factors, a 21.26-$\mu g/m^3$ increment in the 2-day moving average of same-day and previous-day NO_2 concentrations was statistically linked to an increase of 6.38% [95% confidence interval (CI): 1.33%, 11.67%] of AMI hospital admissions. Additionally, per IQR increment in the 2-day moving average exposure of same-day and previous-day NO_2 pollutant levels was linked to a 7.85% (95% CI: 1.19%, 14.95%) increase of AMI hospital admissions among people aged above 65 years old. An effect modification of risk by gender was found, suggesting that females were more susceptible to the exposure to NO_2 pollutant.

Conclusions A statistical association between NO_2 exposure and AMI attack risk is identified, which can provide insight into the planning of clinical services for AMI.

Keywords Air pollution · Acute myocardial infarction · Particulate matter · Nitrogen dioxide · Time series study

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Introduction

A growing number of studies have documented the elevated risk of cardiovascular diseases linked to the exposure to ambient air pollutants over recent years (Huang et al. 2016; Alessandrini et al. 2013; Kan et al. 2008; Wang et al. 2014; Miller et al. 2007). In addition, the effects of the exposure to air pollutants on the morbidity and mortality of cardiovascular diseases have been suggested (Alessandrini et al. 2013; Slaughter et al. 2005; Szyszkowicz 2008; Kloog et al. 2012).

Worldwide, acute myocardial infarction (AMI) is a leading cause of mortality and adult disability (GBD 2013 Mortality and Causes of Death Collaborators 2015; Murray et al. 2012). In China, a recent study from northern cities has investigated the effects of elevated concentrations of particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) on the emergency hospital admissions for AMI, and identified the adverse health effects of air pollution (Liu et al. 2017). A systematic review and meta-analysis has also showed that some of the major air pollutants, with the exception of O_3, were significantly associated with a near-term increase in myocardial infarction risk (Mustafic et al. 2012). Moreover, a study from Australian and New Zealand showed a significant association between the increases in CO, NO_2, and $PM_{2.5}$ concentrations and the risk of adult hospital admissions for myocardial infarction (Barnett et al. 2006). Another study has also suggested the effects of elevated concentrations of $PM_{2.5}$ and NO_2 on the risk of ST elevation myocardial infarction (STEMI) (Argacha et al. 2016).

In regards to southern Chinese cities, several epidemiologic studies have examined the effects of ambient air pollutants on daily mortality in Guangzhou (Argacha et al. 2016; Yang et al. 2012; Li et al. 2016). These early time series studies mainly focused on the daily mortality of diseases as outcome events to examine the adverse health effects of ambient air pollutants. However, more precise effect estimates of air pollutant exposure on the attack risks of cardiovascular diseases, especially for AMI, have been limited by available disease surveillance data of high enough quality and sufficiently large sample size in southern Chinese cities. To the best of our knowledge, the evidence for the association between ambient air pollution and AMI attack risk in South China is still unclear. Therefore, the present study aimed to assess the short-term associations between exposure to air pollutants, including $PM_{2.5}$ (particulate matter < 2.5 μm in diameter), O_3, SO_2, and NO_2, and hospital admission risk of AMI during the period from 2014 to 2017.

Methods

Data

Daily concentrations of $PM_{2.5}$, SO_2, NO_2, and O_3 of interest were available from the Daily Quality Report of the Guangzhou Environmental Protection Bureau during the study period from January 1, 2014, to December 31, 2017. Twenty-four-hour samples of $PM_{2.5}$, SO_2, and NO_2 and 8-h samples of O_3 from 29 air quality monitoring stations (Guo et al. 2018) in Guangzhou were collected, since the air pollution data from these stations during the study period were missing the least. On average, of the total of 1461 daily observations, there was 6.13% missing data of the number of observations across stations. We estimated the missing values of each pollutant using series means for specific calendar months of a year in each station so that daily pollutant data were available throughout the 4-year period of interest. Since each air quality monitoring station respectively collected $PM_{2.5}$, SO_2, NO_2, and O_3 samples, a centering method (Guo et al. 2018) was used to compute the territory-wide mean concentrations of each pollutant to remove the station-specific influence on the measurements of each pollutant. Therefore, daily concentrations of the pollutants of interest were calculated and available for our analysis. All pollutant concentrations are measured in micrograms per cubic meter ($\mu g/m^3$).

The daily mean temperature (°C) and relative humidity (%) were obtained from the China Meteorological Data Sharing System (http://cdc.nmic.cn/home.do) during the study period. The daily mean temperature, relative humidity, and wind speed throughout the 24-h period were adjusted in the models for potential confounding effects.

The daily number of AMI hospital admissions was collected from the Guangzhou Center for Disease Control and Prevention (CDC) by using a standard operation procedure. According to the guidance of the surveillance system, data on demographic characteristics, medical history, and clinical data on symptoms, date of hospitalization, discharge date, and hospitalization expenses and other relevant information for each AMI case were collected. All hospitalizations for AMI cases diagnosed and coded based on the International Classification of Diseases (ICD), Tenth Revision (ICD-10, code I21) were considered. Independent investigators inspected all hospital admissions of AMI, and a sequence of systematic quality control of data was performed to ensure the quality of data.

Statistical analysis

First, a descriptive analysis was used to assess basic characteristics, including gender, age, ethnic group, occupation, and marital status, for each AMI hospital admission by calendar year. The daily number of AMI hospital admissions and daily concentrations of air pollutants of interest were examined with time series plots, respectively.

Second, in order to evaluate the risk of AMI hospital admissions attributable to the exposure to the pollutants of interest, generalized additive models (Pun et al. 2014; Lisabeth et al. 2008) were adopted and established in this study. Smoothing splines with 8 degrees of freedom (dfs) per year for time trend, 3 dfs for current-day temperature and previous 2-day moving average, and 3 dfs for current-day relative humidity and previous 2-day moving average were previously suggested (Peng et al. 2009) and adopted here. The day of the week and public holidays (Wong et al. 2002) were controlled for in our established models.

Our study established unconstrained distributed lag Poisson regression models to estimate the associations between the exposure to the pollutants and hospital admission of AMI. We initially applied single-pollutant models to examine the effect of exposure to the pollutants on AMI risk on the same day (lag_0) and single-day exposure on the previous 1–3 days (lag_1, lag_2, and lag_3, respectively), while adjusting for other time-varying confounders. Then, we focused on the exposure to a 2-day moving average of same-day and previous-day pollutant levels as a priori lag structure. By controlling for other pollutants, we constructed multipollutant models to evaluate the independent association between a pollutant and hospital admission of AMI in the presence of the other pollutants.

Furthermore, we conducted separate analyses for gender and age group (< 66 years old, 66 years old and above). Risk estimates were reported as the percent increase [(relative risk − 1) × 100%] in the daily number of AMI hospital admissions for an interquartile range (IQR) increment in air pollutant concentrations. The Poisson regression models were constructed without adding an offset term, reflecting the plain assumption that the population at risk was relatively constant during the study years (Lisabeth et al. 2008). Time trends, day of the week, public holidays, mean temperature, and relative humidity were controlled for in the models. All statistical analyses were carried out within the R software, version 3.4.0. All statistical tests were two-sided, and a p-value < 0.05 was considered to be statistically significant.

Results

The basic characteristics of AMI hospital admissions by year are shown in Table 1. There were a total of 19,622 hospital admissions during the study period. The average age of AMI

Table 1 Basic characteristics of patients hospitalized for acute myocardial infarction (AMI) by calendar year in Guangzhou, 2014–2017

Characteristic	2014 (n = 3605)	2015 (n = 4858)	2016 (n = 5295)	2017 (n = 5864)
Gender, %				
Male	69.82	69.88	70.76	71.78
Female	30.18	30.12	29.24	28.22
Mean age, years	67.63	68.14	67.84	66.90
Age group in years, %				
< 20	0.06	0.04	0.00	0.00
20–44	5.27	4.88	4.36	6.04
45–54	13.45	12.60	13.48	15.54
55–64	21.72	21.08	22.74	21.79
65–74	22.33	24.29	23.44	22.82
75 above	37.17	37.11	35.98	33.82
Ethnic group, %				
Han	99.61	99.57	99.36	98.48
Minority	0.28	0.25	0.38	0.51
Missing	0.11	0.19	0.26	1.01
Marital status, %				
Married	94.04	93.50	91.94	92.36
Divorced	0.78	0.66	0.93	1.09
Widowed	2.36	2.57	2.66	2.76
Single	1.11	1.11	1.17	1.42
Other	0.17	0.02	0.06	0.00
Missing	1.55	2.14	3.25	2.37
Median duration of hospital stay, days	8.00	8.00	8.00	8.00

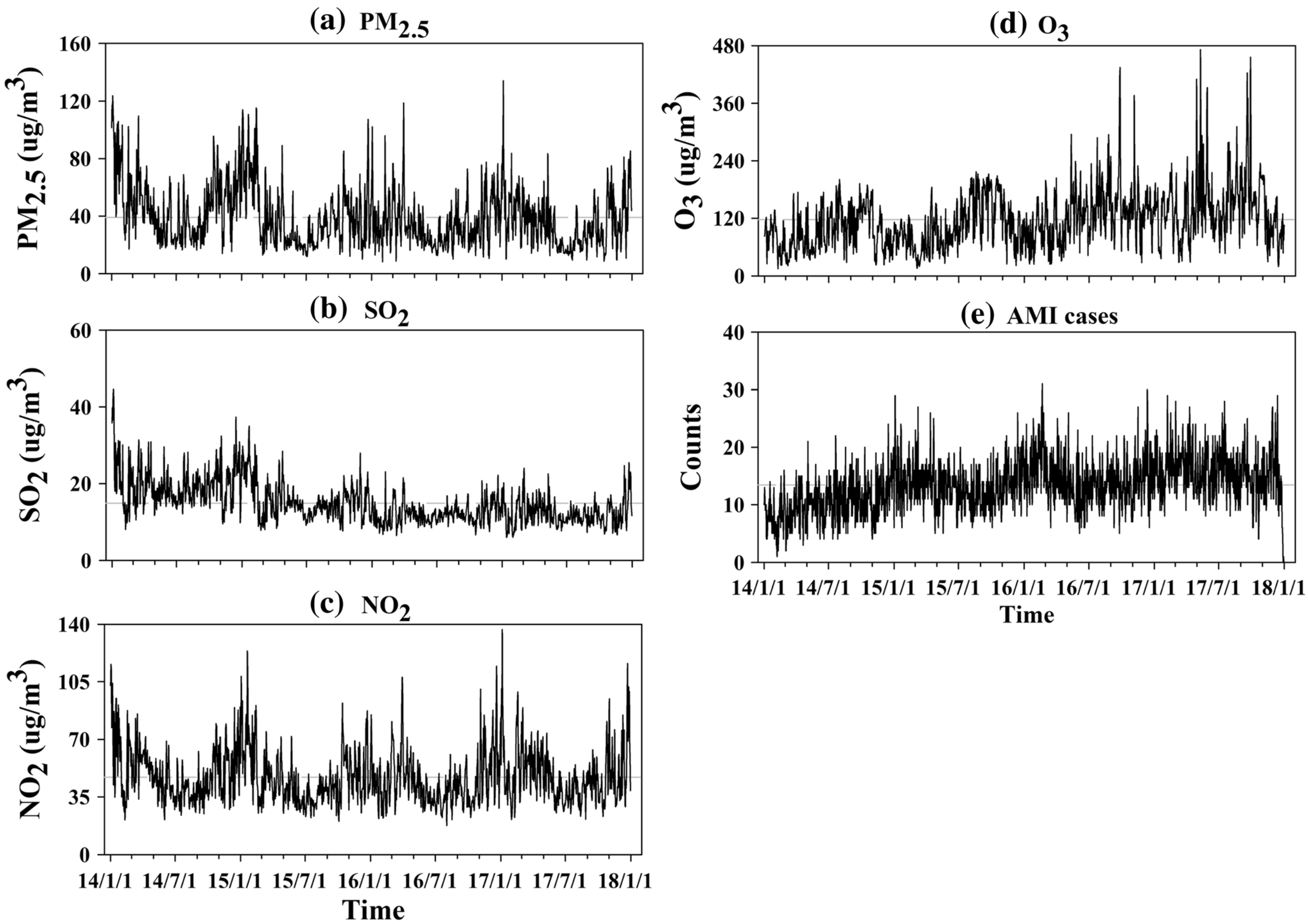

Fig. 1 Daily time series plots of hospital admissions of acute myocardial infarction (AMI) and pollutant ($PM_{2.5}$, SO_2, NO_2, and O_3) concentrations during the study time period of 2014–2017, Guangzhou, China

patients hospitalized in 2014, 2015, 2016, and 2017 was 67.63, 68.14, 67.84, and 66.90 years old, respectively. The number of AMI hospital admissions for males was larger than the figure for females. More hospital admissions of AMI appeared among people aged above 75 years old in relation to the other age groups, and more than 98% were Han Chinese. Among the patients in this study, most of them were married. On average, for each AMI hospital admission, the duration of hospital stay was 8 days.

Time series of the daily number of AMI hospital admissions and daily concentrations of $PM_{2.5}$, SO_2, NO_2, and O_3 are displayed in Fig. 1. The average hospital admission of AMI per day was 13 (standard deviation, 5). The daily average relative humidity and temperature was 79.68% and 22.02 °C, respectively. The daily mean concentrations of $PM_{2.5}$, SO_2, NO_2, and O_3 were 39.02 μg/m^3, 14.85 μg/m^3, 46.86 μg/m^3, and 117.15 μg/m^3, respectively. These results are shown in Table 2.

Table 2 Descriptive statistics of hospital admissions of acute myocardial infarction (AMI), meteorological factors, and concentrations of pollutants ($PM_{2.5}$, SO_2, NO_2, and O_3) in Guangzhou, China, 2014–2017

Variable	Daily mean (SD)	Minimum	Maximum	Interquartile range
No. of hospital admissions	13 (5)	0	31	6
Meteorological measurements				
Relative humidity, %	79.68 (10.18)	31.00	100.00	13.00
Mean temperature, °C	22.02 (6.19)	3.40	31.10	10.30
Pollutant concentrations, μg/m^3				
$PM_{2.5}$	39.02 (20.40)	8.31	134.02	26.13
SO_2	14.85 (5.30)	5.93	44.59	6.41
NO_2	46.86 (16.64)	17.50	136.70	21.26
O_3	117.15 (59.46)	15.31	471.66	78.49

In Fig. 2, we found similar patterns in the associations for which the risk estimates of $PM_{2.5}$, SO_2, NO_2, and O_3 pollutants varied by lag structures according to the single-pollutant models of single-day exposure lags. In addition, there were also significant associations of $PM_{2.5}$ (per 26.13 μg/m^3), SO_2 (per 6.41 μg/m^3), and NO_2 (per 21.26 μg/m^3) with the elevated risk of AMI hospital admission at lag_0 (3.32%, 95% confidence interval [CI]: 0.44%, 6.27%; 3.69%, 95% CI: 0.53%, 6.93%; 4.02%, 95% CI: 1.32%, 6.78%), respectively. The association of NO_2 with elevated risk of AMI hospital admission at lag_1 was also statistically significant.

Figure 3 shows the risk estimates linked to the exposures to a 2-day moving average of same-day and previous-day pollutant levels of $PM_{2.5}$, SO_2, NO_2, and O_3 for AMI hospital admissions in single-pollutant and multipollutant models, respectively. Our results demonstrated that a positive association between the exposure to SO_2 and the risk of AMI hospital admission in the single-pollutant model diminished in multipollutant models. In particular, the exposure to the 2-day moving average of same-day and previous-day NO_2 pollutant was independently associated with the elevated risk of hospital admission of AMI, suggesting that there was an elevated risk (6.38%, 95% CI: 1.33%, 11.67%) of AMI hospital admission in relation to per IQR increment in the concentration of the pollutant.

Finally, we performed subgroup analyses according to the characteristics of gender and age group (< 66 years old, 66 years old and above) (Tables 3 and 4). We identified that there was an effect modification of risk by gender. Per IQR elevation in the 2-day moving average exposure to NO_2 level was linked to a 10.47% (95% CI: 1.03%, 20.81%) increase in hospital admissions for AMI among females. In addition, there was a statistical association between 2-day moving average exposure to NO_2 (7.85%, 95% CI: 1.19%, 14.95%) and hospital admission of AMI among the population aged above 66 years old, indicating that this subgroup of the population is more susceptible to the exposure to NO_2 pollutant.

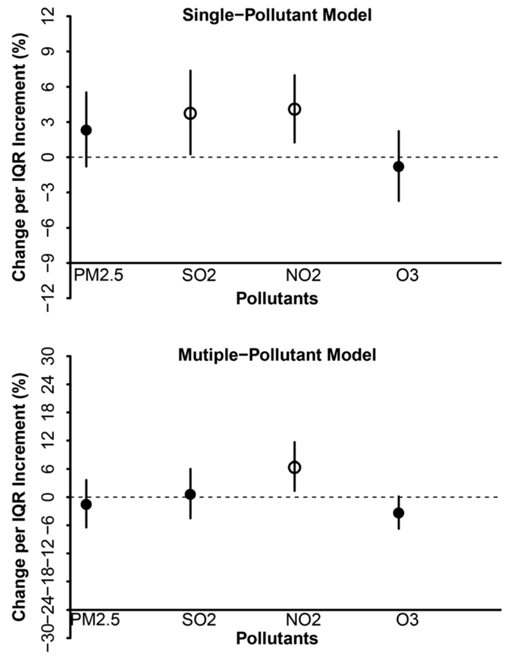

Fig. 3 Percent change in hospital admissions of acute myocardial infarction (AMI) per interquartile range (IQR) increment in 2-day moving average (current day and previous day) of daily $PM_{2.5}$, SO_2, NO_2, and O_3 concentrations according to the single-pollutant and multipollutant models. All models were adjusted for meteorological factors, time trend, day of the week, and public holidays. Statistically significant associations are represented by lines with open circles. The bars denote 95% confidence intervals

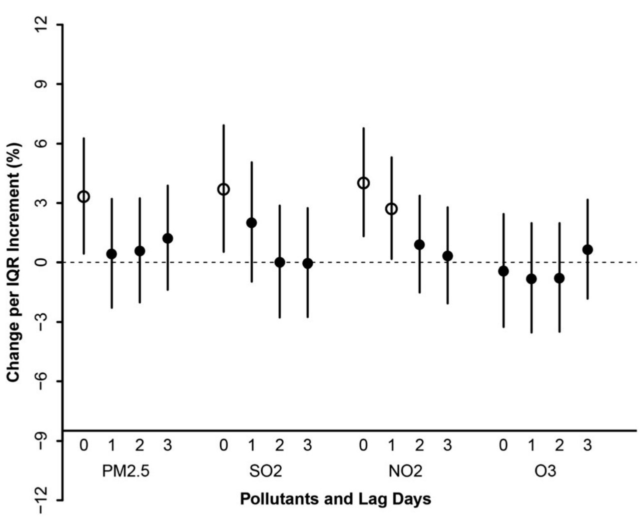

Fig. 2 Percent change in hospital admissions of acute myocardial infarction (AMI) per interquartile range (IQR) increment in $PM_{2.5}$, SO_2, NO_2, and O_3 concentrations at single-day exposure lags [the current day (lag_0) or up to 3 days prior to the current day (lag_3)], based on single-pollutant models adjusted for meteorological factors, time trend, day of the week, and public holidays, Guangzhou, China, 2014–2017. Statistically significant associations are represented by lines with open circles. The bars denote 95% confidence intervals

Table 3 Percent changes with confidence intervals (CIs) in hospital admissions of acute myocardial infarction (AMI) per interquartile range (IQR) increment in the exposure to a 2-day moving average of same-day and previous-day pollutant levels of $PM_{2.5}$, SO_2, NO_2, and O_3 by gender, adjusted for other time-varying confounders, Guangzhou, China, 2014–2017

Pollutants	Male		Female	
	IQR	95% CI	IQR	95% CI
$PM_{2.5}$	− 0.77	− 6.67~5.47	− 3.39	− 12.08~6.11
SO_2	2.12	− 4.06~8.69	− 2.83	− 11.72~6.93
NO_2	4.74	− 1.15~10.98	10.47*	1.03~20.81
O_3	− 4.05	− 8.04~0.08	− 1.66	− 7.98~5.02

*p-Value < 0.05 indicates that the risk estimates are statistically significant

Table 4 Percent changes with confidence intervals (CIs) in hospital admissions of acute myocardial infarction (AMI) per interquartile range (IQR) increment in the exposure to a 2-day moving average of same-day and previous-day pollutant levels of $PM_{2.5}$, SO_2, NO_2, and O_3 by age group (< 66 years old, 66 years old and above), adjusted for other time-varying confounders, Guangzhou, China, 2014–2017

Pollutants	< 66 years old		66 years old and above	
	IQR	95%CI	IQR	95% CI
$PM_{2.5}$	− 4.43	− 11.77~3.48	0.58	− 5.95~7.52
SO_2	5.99	− 2.29~14.95	− 3.11	− 9.52~3.74
NO_2	4.41	− 3.13~12.54	7.85*	1.19~14.95
O_3	− 4.97	− 10.02~0.32	− 1.96	− 6.49~2.75

*p-Value < 0.05 indicates that the risk estimates are statistically significant

Discussion

In summary, this study assessed the associations of an extensive suite of air pollutant exposures with AMI hospital admissions in South China. Our findings revealed that, in the single-pollutant model, hospital admissions of AMI were positively associated with NO_2, and the association persisted in multipollutant models accounting for other potential confounding factors.

Previous reports showed a positive association between elevated levels of gaseous air pollutants and PM with hospital admissions for diseases such as myocardial infarction (Liu et al. 2017; Mustafic et al. 2012; Barnett et al. 2006). A study from Belgian demonstrated a significant association between the increase in $PM_{2.5}$ and NO_2 and hospital admissions for STEMI (Argacha et al. 2016). However, evidence of the associations between air pollutants and daily hospital admissions for AMI using a relatively high quality database of air pollution surveillance is still limited in South China. This is one of the few studies on the short-term effects of ambient air pollutants on hospital admission of AMI based on a large-scale multicenter registry database in the study sites so far.

In fact, waste gas pollution from all kinds of vehicles has become one of the main atmospheric polluters and cause of the concentrations of air pollutants in Guangzhou, and the ambient air quality standards are generally worse than those for USA, Hong Kong, and the European Union (Zhou et al. 2007). This is also pointed out in our previous study (Guo et al. 2018). This present study provided effect estimates of exposures to ambient air pollutants on hospital admissions for AMI. We observed an independent association of the exposures to a 2-day moving average of same-day and previous-day pollutant levels of NO_2 with hospital admission of AMI after controlling for other pollutants and time-varying confounders in the model. Overall, this study suggested that there may be a close relationship between the short-term exposure to NO_2 and hospital admission for AMI.

Our findings showed that a significant association of ambient NO_2 concentrations and hospital admission of AMI persisted in Guangzhou, irrespective of single-pollutant or multipollutant models. Some previous studies have assessed the hazard of exposure to NO_2 and found a significant link between the exposure and respiratory illnesses emergency department visits and hospitalizations (Li et al. 2011; Liu et al. 2016). For cardiovascular diseases, the adverse health effects of exposure to NO_2 associated with the disease mortality relative risk were suggested in China (Luo et al. 2016; Liu et al. 2015). As one of the most common cardiovascular emergencies, AMI is thought to create a heavy burden of disease in the world (GBD 2013 Mortality and Causes of Death Collaborators 2015; Murray et al. 2012). A recent study from northern cities in China has identified the adverse health effects of elevated concentrations of NO_2 on the emergency hospital admission of AMI (Liu et al. 2017), which is basically consistent with the findings of this study. However, the previous study (Liu et al. 2017) from northern cities in China also found that an IQR increase in PM_{10}, SO_2, and CO concentrations was significantly associated with an increase in AMI admissions, respectively. However, these associations were not found in our study. Continuous studies based on larger and multicenter studies should be performed to evaluate these associations in the future.

Our findings add to those previously reported in several ways. First, this is one of the few studies that provides evidence on the association between short-term exposure to the pollutant NO_2 and the hospitalization risk of AMI. Second, information based on a relatively large number and high quality of air pollution surveillance and health outcome records were used to improve the estimates of air pollution-related health effects in this study.

This study does have several limitations however. First, this is a retrospective ecological study and the ecological fallacy cannot be ruled out, which does have an impact on our estimation of the results. Second, personal exposure levels of air pollution may be affected by personal behavior, such as duration of outdoor activity or frequency of the use of air purifiers. This may also have a potential impact on the magnitude of the estimated associations between AMI hospitalization risks and the exposure to air pollution. Third, although air pollution surveillance data from a set of air quality monitoring stations were used and the missing data for air pollutants were interpolated using month-specific series means, missing values contained in air pollution data may affect our estimation of the results. Fourth, although a sequence of data management was performed to ensure the data quality of AMI hospital admission records, measurement errors cannot be completely eliminated from our study since data in the hospital admission records usually induce biases due to some system-specific factors, including admission policies and reporting practices among different hospitals. This concern has also been suggested in our previous study (Guo et al. 2018). In total, our findings simply suggested that there was a statistically significant association between the exposure to ambient NO_2 and hospital admission of AMI in Guangzhou. The mechanisms for the association should be investigated in the future.

Conclusions

An elevated risk of hospital admission of acute myocardial infarction (AMI) in relation to the ambient nitrogen dioxide (NO_2) exposure in Guangzhou was identified in this study. The result lends support to the growing body of literature concerning the adverse effects of NO_2 and also provides insight into the planning of clinical services for air pollution exposures.

Acknowledgements We thank the Guangzhou Environmental Protection Bureau and the China Meteorological Data Sharing System for providing the data used in this study. This work was supported by the National Natural Science Foundation of Guangdong Province (no. 2018A030313928). The funder had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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