ORIGINAL RESEARCH

The Effects of Air Pollution on Cardiovascular and Respiratory Causes of Emergency Admission

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Abstract

Introduction: Today, air pollution is one of the critical problems in metropolitans and necessary preparations are needed for confronting this crisis. The present study was based on the goal of determining the relationship of air pollutant levels with the rate of emergency admissions for respiratory and cardiovascular patients. **Methods:** In the present retrospective cross-sectional study, all respiratory and cardiovascular patients, referred to emergency department during 2012, were assessed. The meteorological and air pollution data were collected. Information regarding the numbers and dates (month, day) of admission for respiratory and cardiovascular diseases was achieved from the hospital's electronic registration system. The relation of air pollution and respiratory and cardiovascular admissions were analyzed by generalize additive model (GAM). **Results:** 5922 patients were assessed which included 4048 (68.36%) cardiovascular and 1874 (31.64%) respiratory. Carbon monoxide (CO) level was an independent risk factor of cardiovascular disease on the same day (RR=1.49; 95% CI: 1.25- 1.77; P<0.001), the day before (RR=1.22; 95% CI: 1.02- 1.45; P=0.03), and the last two days (RR=1.3; 95% CI: 1.09- 1.54; P<0.001). The same process was repeated for ozone (O$_3$). In addition, the O$_3$ level on the same day (RR=1.49; 95% CI: 1.25- 1.77; P<0.001), the day before (RR=1.22; 95% CI: 1.02- 1.45; P=0.03), the last two days (RR=1.3; 95% CI: 1.09- 1.54; P<0.001), and the last week (RR=1.004; 95% CI: 1.0007-1.008; P=0.02) were independent risk factors of respiratory admissions. The increased level of particulate matter less than 2.5 micrometers in diameter (PM$_{2.5}$) like O$_3$ led to growth in the admissions to emergency department. **Conclusion:** The findings of the present study suggested that rising levels of CO and O$_3$ during two days leads to a significant increase in cardiovascular admission on the third day. Furthermore, increase in O$_3$, PM$_{2.5}$, nitrogen dioxide (NO$_2$), and CO levels causes a rise in respiratory admissions to emergency department.

Key words: Air pollutant; patient admission; cardiovascular disease; respiratory disease

Introduction:

Air pollution is a complicated and heterogeneous mixture of gases, liquids, and particulate matter (PM) which is known as one of the risk factors of cancers, respiratory and cardiovascular diseases (1-4). During the past 20 years, numerous epidemiologic reports have shown a growing concern related to possible dangerous effects of air pollution on cardiovascular diseases (5, 6). Among these pollutants, more attention has been paid to carbon monoxide (CO), nitrogen oxides (NO$_x$), sulfur oxide (SO$_2$), ozone (O$_3$), Lead, and thoracic particles such as particulate matter less than 10 mi-

crometers in diameter (PM$_{10}$) and fine particles like particulate matter less than 2.5 micrometers in diameter (PM$_{2.5}$) (7-10). The findings of these studies are representative of the direct relation between the levels of these molecules in the air and the rate of admission as well as mortality of cardiovascular diseases (11). Therefore, the cardiac causes of mortality were exacerbated even with short-term increase in these components (12-14). However, little information has been achieved about the air pollution morbidity most of which relate to decades of 1990 and 2000. Since the levels of SO$_2$, PM$_{10}$, and PM$_{2.5}$ have noticeably increased in recent years (15), further assessment of this relationship is highly important.

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Today, air pollution is recognized as a crisis in metropolitans and necessary preparations are required for confronting this problem. Preparation of health care systems to control and treat diseases risen from air pollution is very significant in management of these patients. Awareness of patient admissions has a remarkable role in providing proportional equipment and facilities fitted with the number of admitted patients. On the other hand, because of differences in pollutant levels of various geographical locations, the pattern of hospital admissions may have a noticeable difference on polluted days (16). Therefore, it is critical for health care systems to be informed of the pattern of hospital admissions in polluted days to program more accurate man agent plan. The present study was done based on the goal of determining the relationship of air pollutant levels with the rate of emergency admissions for respiratory and cardiovascular patients.

Methods:

Study design and setting:

In this retrospective cross- sectional study, the association between air pollutant levels with respiratory and cardiovascular diseases has been evaluated in patients referred to the emergency department of Bessat hospital, Tehran, Iran, during 2012. Tehran, the capital of Iran, is the most air-polluted city in this country and most of its pollution results from traffic and transport. About 8.5 million people live in this city and make up more than 10% of Iran's population.

Patients

The studied population were patients referred to the emergency department with diagnosis of non-traumatic cardiovascular and respiratory disease from April 2012 to April 2013. Exclusion criterion was uncertainty of diagnosis.

Hospital Admissions

Information of daily admissions of respiratory and cardiovascular diseases was achieved from hospital's electronic registration system. At first, the numbers and dates (month, day) of admissions were extracted. Myocardial infarction, ischemic attacks, angina pectoris, coronary cardiovascular disease, cardiomyopathy, heart failure, cardiac dysrhythmia, endocarditis, and myocarditis were counted as cardiovascular disease. In addition, asthma, emphysema, allergies, bronchitis, obstructive pulmonary disease, respiratory infections, and

Table 1: The status of emergency admission and air pollutants during study period ⇧

Variable	Mean±SD	Min	Centile 25	Median	Centile 75	Max
Emergency Admission						
Cardiac	11.06±2.05	5	10	11	12	16
Respiratory	5.12±1.75	2	3	5	6	10
Total	16.18±1.85	12	15	16	18	21
Air pollutants concentrations						
CO ($\mu g/m^3$)	3.7±0.88	1.9	3	3.6	4.3	6.5
NO_2 ($\mu g/m^3$)	47.58±11.68	18	38	47	56	78
O_3 ($\mu g/m^3$)	37.08±11.6	12	27	38	45	70
SO_2 ($\mu g/m^3$)	32.22±4.67	20	29	32	35	50
$PM_{2.5}$ ($\mu g/m^3$)	98.77±23.9	42	83	95	110	192
PM_{10} ($\mu g/m^3$)	64.72±19.49	24	42	62	71	201
Meteorological measures						
Temperature (°C)	19.6±9.43	-2	10.3	21.2	28.9	41.3
Humidity (%)	48.97±15.28	20	40	50	60	79
Wind speed (km/h)	17.7±5.55	10	13	17	22	34

SD: Standard deviation; CO: carbon monoxide; NO_2: nitrogen oxide; O_3: ozone; SO_2: sulfur oxide; $PM_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM_{10}: like particulate matter less than 10 micrometers in diameter.

Table 2: correlation matrix between air pollutants and meteorological variables ⇧

	CO	O_3	SO_2	NO_2	PM_{10}	$PM_{2.5}$	Temperature	Wind speed	Humidity
CO	1.00	-	-	-	-	-	-	-	-
O_3	0.05	1.00	-	-	-	-	-	-	-
SO_2	0.42[a]	-0.05	1.00	-	-	-	-	-	-
NO_2	0.38[a]	0.47[a]	0.39[a]	1.00	-	-	-	-	-
PM_{10}	0.43[a]	0.03	0.54[a]	0.40[a]	1.00	-	-	-	-
$PM_{2.5}$	0.23[a]	0.39[a]	0.36[a]	0.54[a]	0.54[a]	1.00	-	-	-
Temperature	-0.23[a]	-0.38[a]	0.01	-0.32[a]	-0.04	-0.23[a]	1.00	-	-
Wind speed	-0.14[b]	-0.16[b]	-0.06	-0.07	0.06	-0.04	0.42[a]	1.00	-
Humidity	0.12[c]	0.25[a]	-0.12[c]	0.17[b]	-0.03	0.18[a]	-0.62[a]	-0.34[a]	1.00

a: p<0.001; b: p<0.01; c: p<0.05; CO: carbon monoxide; NO_2: nitrogen oxide; O_3: ozone; SO_2: sulfur oxide; $PM_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM_{10}: like particulate matter less than 10 micrometers in diameter.

Table 3: The correlation between enviromental pollutants and cardiovascular admissions in the studied hospital ⇧

Variable	Adjusted Relative risk	95% confidence Interval	P[a]
Lag 0			
CO	1.49	1.25-1.77	<0.001
O3	1.02	1.01-1.03	<0.001
NO2	1.001	0.98-1.03	0.01
SO2	0.998	0.97-1.03	0.94
PM10	0.99	0.98-1.01	0.41
PM2.5	1.004	0.99-1.02	0.53
Lag 1			
CO	1.22	1.02-1.45	0.03
O3	1.01	1.001-1.02	0.03
NO2	1.00	0.98-1.02	0.94
SO2	0.99	0.96-1.02	0.64
PM10	0.98	0.98-1.01	0.06
PM2.5	1.01	0.99-1.02	0.35
Lag 2			
CO	1.30	1.09-1.54	<0.001
O3	1.01	1.001-1.02	0.02
NO2	0.99	0.96-1.01	0.25
SO2	0.99	0.96-1.02	0.37
PM10	1.00	0.98-1.02	0.94
PM2.5	1.00	0.99-1.01	0.69
Lag 7			
CO	0.97	0.88-1.08	0.60
O3	0.99	0.99-1.002	0.19
NO2	1.01	0.99-1.02	0.13
SO2	1.001	0.98-1.02	0.96
PM10	1.003	0.99-1.01	0.41
PM2.5	1.00	0.99-1.002	0.36

a: Adjusted for temperature, wind speed, humidity and other air pollutants. CO: carbon monoxide; NO_2: nitrogen oxide; O_3: ozone; SO_2: sulfur oxide; $PM_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM_{10}: like particulate matter less than 10 micrometers in diameter.

pneumonia were considered as respiratory problems.

Air pollution and meteorological characteristics

There are 31 air quality-monitoring stations in Tehran city, recording data 24 hours per day. These stations check the levels of CO, PM_{10}, $PM_{2.5}$, NO_2, O_3, and SO_2 each hour. In the present study, these data were used to calculate the average of pollutant concentrations during 24 hours.

It is worth noting that meteorology organization of Tehran measures the average of humidity, temperature, and wind speed, hourly. There are 13 meteorology stations in the province five of which are specifically representative of meteorological situations of Tehran city. The data of these five stations were extracted and used.

Statistical analysis

Descriptive statistics and correlation among emergency admissions, air pollutants, and meteorology factors (temperature, humidity, and wind speed) were analyzed using SPSS statistical software version 21.0. Relative risks of respiratory and cardiovascular admissions were calculated by generalize additive model (GAM) based on Poisson distribution; because the previous studies showed that the distribution of pollutants' data didn't follow the normal pattern (5, 6). Each GAM was fitted based on the logarithm of the emergency admission numbers as well as the overall adjusted and linear effects of predictive factors (air pollutants). Therefore, smoothing spline functions were applied to temperature, wind speed, and humidity as confounding factors. Degree of freedom was defined in terms of Akaike's criterion (17). The daily levels of pollutants for the same day (Lag0), the average of the day before and same day (Lag1), average of the last two days (Lag2), and average of the last week (Lag7) were analyzed and the association of pollutant levels with number of daily emergency admissions were evaluated in each period. All the findings were presented as relative risk (RR) and 95% confidence intervals (95% CI). In all analyses p<0.05 was defined as significance level.

Results:

In the present study, the data of daily air pollutant levels, humidity, temperature, and wind speed during 2012 were collected. In total 5922 patients were assessed including 4048 (68.36%) cardiovascular and 1874 (31.64%) respiratory. The admission numbers of cardiovascular patients in winter was significantly low-

er than other seasons (10.3 admissions per day) (df: 3, 362; F=23.24; p=0.0007). The average humidity in the study period was 48.97±15.26 percent and the average of maximum wind speed was 17.7±5.55 kilometers per hour. The findings of this study revealed that with humidity increasing (r=0.35; p<0.001) the rate of respiratory diseases grew, while the wind speed had an inverse relation with admission numbers of respiratory patients (r=-0.16; p=0.002). The wind speed (r=0.097; p=0.06) and humidity (r=-0.06; p=0.23) did not have a significant correlation with cardiovascular admissions. Table 1 shows the respiratory and cardiovascular admission status along with air pollutant levels during the study period.

Table 2 shows the correlation among air pollution indicators. Based on this table, $PM_{2.5}$ and NO_2 have a correlation with other pollutants. The strongest relationships were seen between PM_{10} and $PM_{2.5}$ (r=0.54; p<0.001), NO_2 and $PM_{2.5}$ (r=0.54; p<0.001), and NO_2 and O_3 (r=0.47; p<0.001). All pollutant levels except PM_{10} have a significant relation with relative humidity.

The air pollutant levels and cardiovascular emergency admissions

The findings of the present study showed that cardiovascular admissions to emergency department have a significant association with increasing pollutant levels (Figure 1 and Table 3). After adjusting the analysis for season, temperature, wind speed, humidity, and other air pollutants, the CO level on the same day (RR=1.49; 95% CI: 1.25- 1.77; P<0.001), the day before (RR=1.22; 95% CI: 1.02- 1.45; P=0.03), and the last two days (RR=1.3; 95% CI: 1.09- 1.54; P<0.001) were independent risk factors of cardiovascular admissions. The same pattern was seen for O_3. Other air pollutants did not have any effects on cardiovascular admissions.

### The air pollutant levels and respiratory emergency admissions

Respiratory admissions to emergency department also had a significant relationship with increasing pollutant levels (Figure 2 and Table 4). After adjusting the analysis for season, temperature, wind speed, humidity, and other air pollutants, the O_3 level on the same day

Table 4: The correlation between enviromental pollutants and respiratory admissions in the studied hospital ⇧

Variable	Adjusted Relative risk	95% confidence Interval	P^a
Lag 0			
CO	1.04	1.002-1.09	0.04
O_3	1.01	1.008-1.015	<0.001
NO_2	1.01	1.002-1.01	0.01
SO2	0.99	0.985-1.00	0.05
PM_{10}	0.998	0.996-1.001	0.33
$PM_{2.5}$	1.002	1.001-1.004	0.01
Lag 1			
CO	1.04	0.999-1.08	0.06
O3	1.005	1.002-1.009	<0.001
O_3	1.002	0.998-1.006	0.24
NO_2	0.998	0.99-1.005	0.62
SO2	0.999	0.996-1.002	0.62
PM_{10}	1.002	1.0003-1.004	0.02
Lag 2			
CO	1.04	1.001-1.085	0.04
O_3	1.007	1.003-1.01	<0.001
NO_2	1.0004	0.996-1.005	0.84
SO2	0.995	0.988-1.003	0.21
PM_{10}	0.999	0.997-1.002	0.71
$PM_{2.5}$	1.002	1.001-1.004	0.01
Lag 7			
CO	1.03	0.99-1.07	0.14
O_3	1.004	1.0007-1.008	0.02
NO_2	1.005	1.0006-1.009	0.03
SO2	0.998	0.993-1.007	0.00
PM_{10}	0.999	0.996-1.002	0.77
$PM_{2.5}$	1.002	1.001-1.004	0.01

a: Adjusted for temperature, wind speed, humidity and other air pollutants. CO: carbon monoxide; NO_2: nitrogen oxide; O_3: ozone; SO2: sulfur oxide; $PM_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM_{10}: like particulate matter less than 10 micrometers in diameter
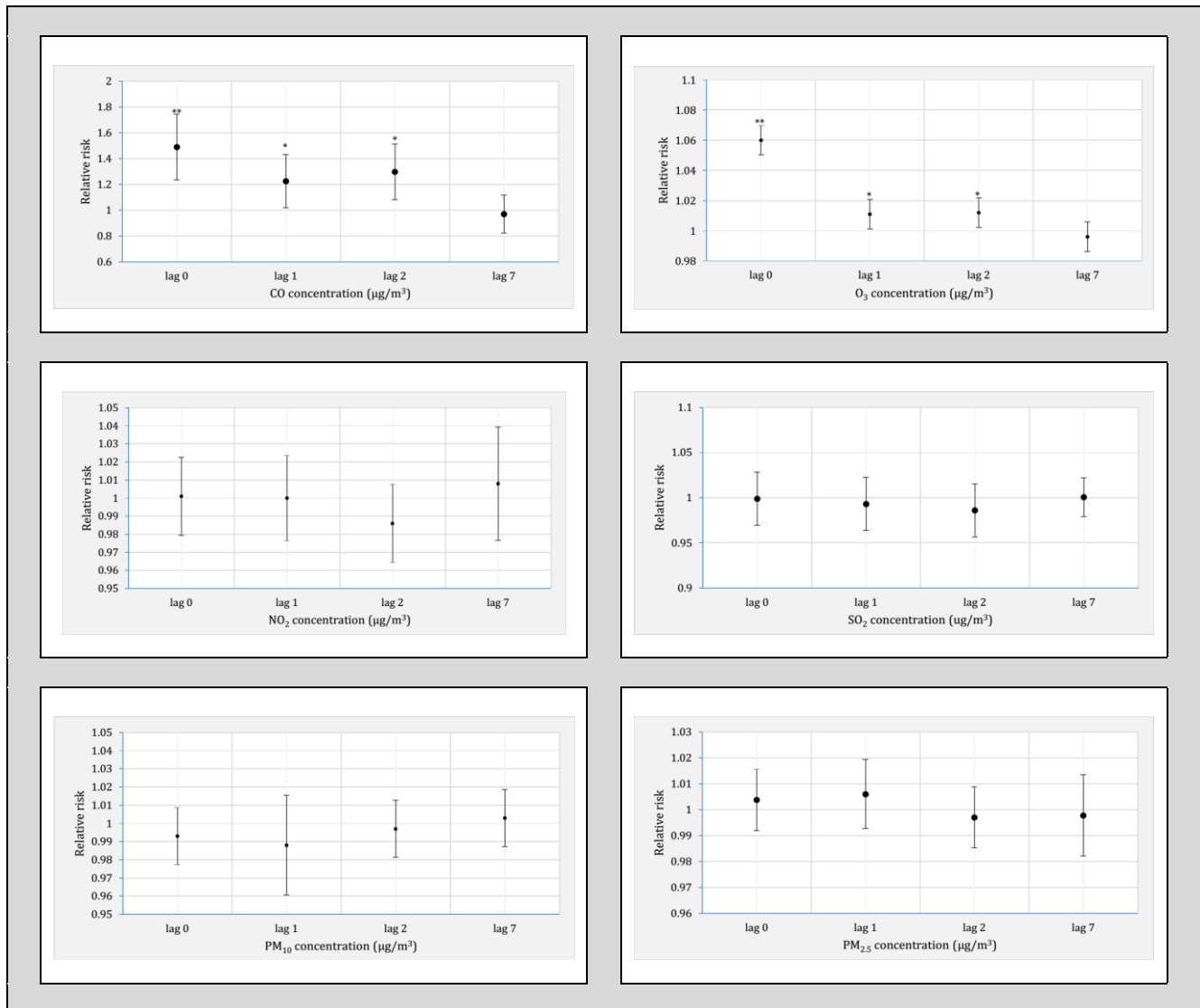
Figure 1: The relation between cardiovascular admissions and air pollutant levels. ** Statistically Significant at level of p<0.001; * Statistically Significant at level of p<0.05 CO: carbon monoxide; NO_2: nitrogen oxide; O_3: ozone; SO_2: sulfur oxide; $PM_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM_{10}: like particulate matter less than 10 micrometers in diameter. ⇧

(RR=1.49; 95% CI: 1.25- 1.77; P<0.001), the day before (RR=1.22; 95% CI: 1.02- 1.45; P=0.03), the last two days (RR=1.3; 95% CI: 1.09- 1.54; P<0.001), and the last week (RR=1.004; 95% CI: 1.0007-1.008; P=0.02) were independent risk factors of admission.

Increased level of $PM_{2.5}$ led to a growth in the admissions to emergency department with respiratory causes just like O_3. Altered levels of NO_2 and SO_2 did not have any effects on respiratory admissions.

Discussion:

The findings of the present study revealed that air pollutant levels have a direct relationship with the number of respiratory and cardiovascular admissions. The in-creased levels of NO and O_3 in the two days before admission, caused a significant increase in cardiovascular admissions. Similarly, increased O_3, $PM_{2.5}$, CO, and NO_2 levels were associated with more respiratory admissions to emergency.

In several studies, CO was mentioned as the most effective pollutant on hospital admissions. For example, in a study Qorbani et al. showed that there is a significant relationship between acute coronary syndrome and the CO level in Tehran citizens. Also, it was suggested that there was no correlation between the increased levels of PM_{10} and $PM_{2.5}$ and coronary heart disease (7). Hosseinpoor et al. displayed that the relative risk of angina

pectoris increased with higher CO levels in the two days before admission. This group didn't find any associations between the rate of angina pectoris and other pollutants (11). Furthermore, in this study CO level had the closest relation with cardiovascular diseases with O_3 in the second rank. Although in some studies (7, 11), there was no association seen between O_3 and emergency-Admissions with cardiovascular disease. Destructive effects of these pollutants on cardiovascular system has been recognized since many years ago. For example, a review study showed that O_3 was one of the most toxic components of mixed photochemical of air (14). Thus, its increase in air resulting in more the hospital admissions is not too far-fetched. On the other hand, because

of further urbanization of Tehran, ozone level has remarkably increased in recent years. Qorbani et al. (7) reported the average of ozone levels 9.7 μg/m^3 in 2001, while in the present study, the annual average of this component was 37.08 μg/m^3. Although some studies revealed that short-term exposure to particulate matters, increases the risk for cardiovascular admission but the present study did not find any relationship between them. Dominici et al. suggested that the levels of these pollutants are associated with increased cardiovascular admissions (18). In contrast, Hosseinpoor et al (11) and Chen et al (19) found no significant effects. This may be due to misclassification of the average population exposure to particulate matters (20). In addition, some stud-
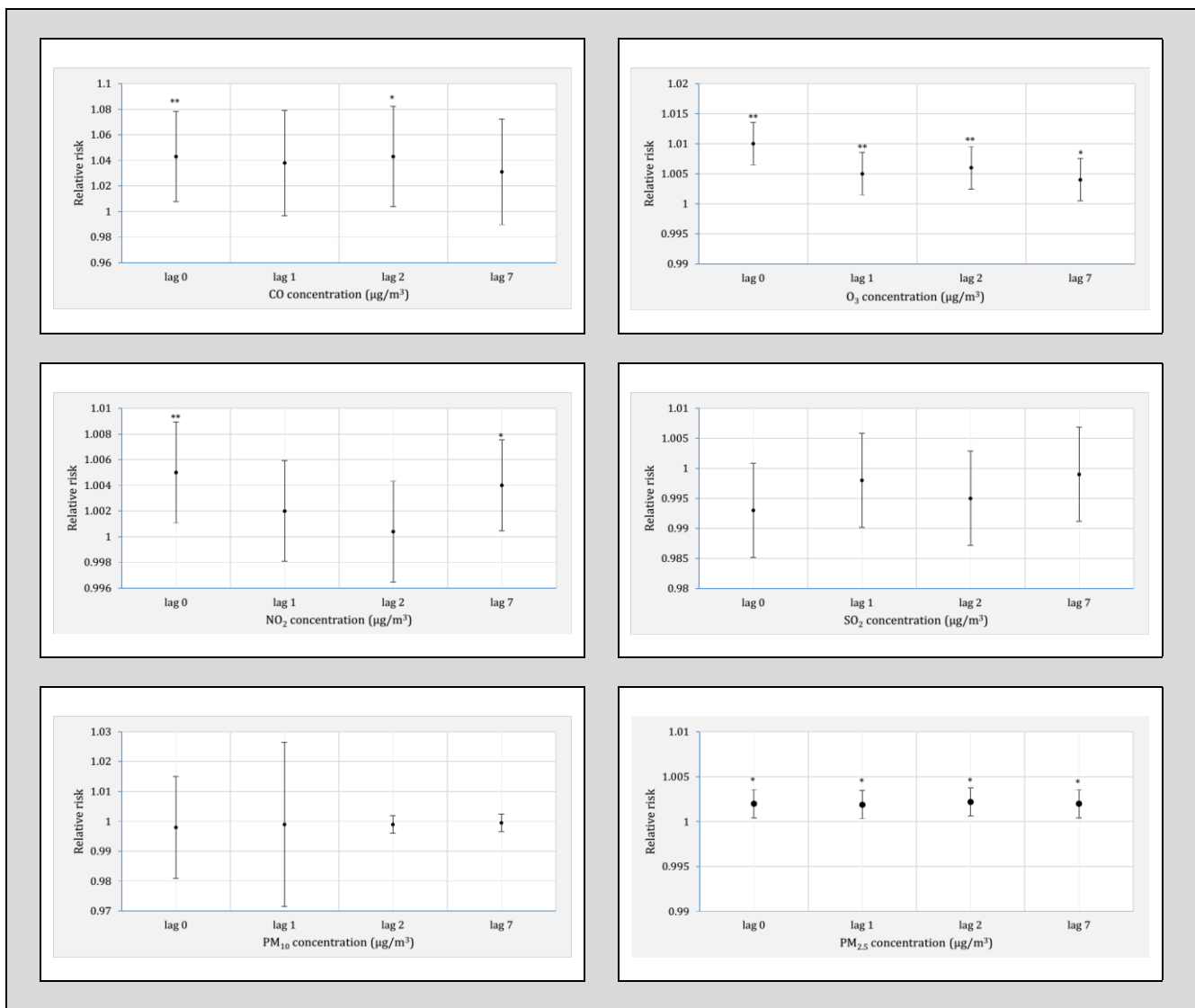
Figure 2: The relation between respiratory admissions and air pollutant levels. ** Statistically Significant at level of p<0.001; * Statistically Significant at level of p<0.05 CO: carbon monoxide; NO$_2$: nitrogen oxide; O$_3$: ozone; SO$_2$: sulfur oxide; PM$_{2.5}$: like particulate matter less than 2.5 micrometers in diameter; PM$_{10}$: like particulate matter less than 10 micrometers in diameter. ⇧

ies have stated that biological variables such as ventilation, time spent outdoors, and household characteristics, affect the strength of these associations. So, for certain individuals and cohorts the health effects attributed to particulate matter might vary in different geographic areas (21).

Air pollution is one of the significant environmental risk factors of acute and chronic respiratory disease. The present project revealed that increased levels of O_3, $PM_{2.5}$, and CO aligned with more emergency admissions due to respiratory diseases. The role of ozone in higher respiratory admissions arose from the effect of this pollutant on increasing inflammation in the respiratory tract (12) which is critical in respiratory disease symptoms. In addition, ozone reduces the respiratory function, increases the activity of respiratory tracts, and asthma. This component leads to increased emergency admissions with respiratory disease in adults and children (22). Burnett and his colleagues showed that one hour increase in the ozone level during the last five days caused 35% increase in emergency admissions for children less than two years of age (12). Ji et al. in their meta-analysis displayed that 10 parts-per-billion increase in ozone leads to 3% increase in respiratory causes of emergency referrals (15). Lin et al. also revealed that there is a strong association between increased level of ozone and clinical admissions for respiratory diseases (6).

$PM_{2.5}$, like ozone, has a remarkable role in respiratory symptoms. Dominici et al. showed that $PM_{2.5}$ has a close association with increased emergency admissions because of obstructive lung diseases and lung infections (18). Similarly, Lall et al. suggested that there is an interconnection between $PM_{2.5}$ level and emergency admissions for respiratory diseases (23). The present study showed similar results, too.

There are several disagreements regarding the correlation between levels of other pollutants and respiratory emergency admissions. Chen et al. presented that NO_2, PM_{10}, and SO_2 levels don't have a correlation with respiratory diseases in Shanghai, China (19). Whereas Tao et al. showed that a strong association exists between these three pollutants and respiratory diseases in Lanzhou, China. This issue was raised due to the difference among pollutant levels in various urban areas. NO_2 had a significant relation with respiratory admissions in this study.

Conclusion:
The findings of the present study suggested that raised levels of CO and O_3 during two days leads to a significant increase in cardiovascular admissions. Furthermore, increased O_3, $PM_{2.5}$, NO_2, and CO levels cause a rise in respiratory admissions to emergency department.

Acknowledgments:

Authors' contributions:
All authors passed four criteria for authorship contribution based on recommendations of the International Committee of Medical Journal Editors.

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